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ABSTRACT

The structure of knowledge in a particular subject-matter discipline and the structure of behavior in a given task-skill domain are often regarded as unrelated or even antithetical bases for the systematic design of instructional products and procedures. This volume documents progress toward a methodology of instructional design founded on the premise that both learning to know and learning to do are essential to the effectiveness of a given course of instruction. Briefly described, the methodology involves three distinct but interrelated techniques of analysis: content, task, and skills. The papers in part 1 present the theoretical rationale underlying the proposed methods and describe the procedure for skills analysis. The papers in Part 2 illustrate applications of content, task, and skill analysis in the science inquiry area at the primary grade level. (Author/HMV)

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THE INTEGRATION OF CONTENT, TASK, AND SKILLS ANALYSIS TECHNIQUES IN INSTRUCTIONAL DESIGN

Edited by David W. Bessemer and Edward L. Smith

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1972 SWRL WORKING PAPERS

COMPUTER-BASED SYSTEMS TO FACILITATE INSTRUCTIONAL DEVELOPMENT

Joseph F. Follettie and Frank Teplitzky, editors

DESIGN OF AN INSTRUCTIONAL MANAGEMENT SYSTEM

John F. McManus, editor

THE INTEGRATION OF CONTENT, TASK, AND SKILLS ANALYSIS TECHNIQUES IN INSTRUCTIONAL DESIGN

David W. Bessemer and Edward L. Smith, editors

PROTOTYPE TESTING IN INSTRUCTIONAL DEVELOPMENT

Fred C. Niedermeyer, editor

PREFACE

The documentation of large-scale development endeavors in education is a phenomenon with which the educational R&D community has had modest experience, since there has been little large-scale development to document. SWRL documentation experience confirms the applicability of Derek Price's conclusion regarding the literature of research and the literature of development.

> A scholarly publication is not a piece of information but an expression of the state of a scholar or a group of scholars of a particular time. We do not, contrary to superstition, publish a fact, a theory, or a finding, but some complex of these . . . . If the paper is an expression of a person or several persons working at the research front, we can tell something about the relations among the people from the papers themselves . . . . It seems that technologists differ markedly from both scientific and nonscientific scholars. They have a quite different scheme of social relationships, are differently motivated, and display different personality traits [Price, 1970, pp. 7-9].

> Clearly, the published paper is not, in general, the end product of a worker in a technological subject; he appears to be instead concerned chiefly with the production of an artifact or process. What then is the role of literature in technology? I suggest that for the most part it is produced as an epiphenomenon. It comes about because many technologists have had scientific training and know full well the code of behavior of the scientist in which publication is not merely right and proper, but a high duty and a behavior expected by peers and employers . . . . In general new technology will flow from old technology rather than from any interaction there might be between the analogous but separate structures of science and technology [Price, 1965, pp. 560-561].

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SWRL experience has been that the course of a well-managed development effort produces considerable documentation but that a good deal of the substance of the information exceeds structures and strictures of journal publication. The journal article constitutes an available medium, but the laundering of the information required to use the medium often washes out the message.

SWRL has found it unproductive to treat information and documentation in the abstract as a "communication problem." A more useful approach is to consider operational means of making information pertinent to large-scale development in education conveniently available to interested audiences. This perspective directs attention to specifying interested audiences and devising communication compatible with their need-to-know characteristics. SWRL information architecture recognizes several audiences.

Staff involved in the development per se and the contract sponsor are two of the most immediate audiences addressed by SWRL documentation. Communication relevant to these audiences is handled by SWRL Technical Notes and Technical Memoranda that chronicle the course of SWRL R&D. These documents range in length from a few to a few hundred pages depending upon their nature. Some 200 of these Technical Notes and Technical Memoranda are issued during the course of a year--a stack several feet tall.

A third audience is the invisible colleges in which SWRL staff actively participate. Collegial exchange of selected Technical Notes and Technical Memoranda serve this audience adequately.

Another audience is product users. A volume of product working papers that brings together the documents associated with the development of each product is issued at the time the product is made available for general use and provides relevant information for this audience.

This leaves the general audience of students, scholars, and other members of the R&D community in education. SWRL Technical Reports and Professional Papers, largely accessed via the ERIC system, are directed to this broad audience. Journals, professional meetings, and other classical scientific and technical information exchange mechanisms are also used.

But each of these mechanisms involves a packing and rationalizing of information into independent pieces that inherently involves time delays and loses some of the original flavor of the work in the process. To reduce the time interval and retain the freshness of the work, an Annual Working Papers series has been initiated. The thematic topics that provide convenience categories for representing inquiry completed during the past year that is of timely interest to a sector of the educational R&D community will be identified. The documents relevant to these topics will then be organized into the volumes constituting the Annual Working Papers for that year. "The Integration of Content, Task, and Skills Analysis Techniques in Instructional Design" is one of four such volumes for the year 1972. The other three volumes of the 1972 SWRL Working Papers, available through the ERIC system, include the following titles:

Prototype Testing in Instructional Development
(Fred C. Niedermeyer, editor)

Computer-Based Systems to Facilitate Instructional Development
(Joseph F. Follettie and Frank Teplitzky, editors)

Design of an Instructional Management System
(John F. McManus, editor)

CONTENTS

THE INTEGRATION OF CONTENT, TASK, AND SKILLS ANALYSIS TECHNIQUES IN INSTRUCTIONAL DESIGN

David W. Bessemer and Edward L. Smith

The structure of knowledge in a particular subject-matter discipline and the structure of behavior in a given task-skill domain are often regarded as unrelated or even antithetical bases for the systematic design of instructional products and procedures. In a more balanced view, both kinds of structure are complementary facets of a well-organized instructional system. But an adequate methodology for integrating the two structures remains to be demonstrated.

The present volume documents progress toward a methodology of instructional design founded on the position that both learning to know and learning to do are essential to the effectiveness of a given course of instruction. The methodology developed thus far deals with the organization of a coordinated structure of knowledge and behavior representative of proficiency in a specific subject-matter area. The methodology does not yet provide routine procedures for the derivation of instructional products and procedures, but lays the foundation for such procedures.

The approach taken here developed out of points of view from many sources; the work of Kuhn and Schwab on the structure of knowledge; the work of Gagné, Scandura, and others on task-skills analysis, types of learning, and the role of transfer in instruction; the work of Tyler, Bloom, and others on the specification of instructional domains; and the work of Simon, Hunt, and others on an information processing approach to the analysis of behavior. All of these aspects are brought together into a coherent methodology through the following basic assumptions:

1. Any subject-matter discipline is unified by a set of inter-related specialized conceptual systems.
2. Many of the specialized conceptual systems of a discipline share common logical structures, and can be categorized by a few types of structural forms.
3. Knowledge of a conceptual system and abilities in using that system can be inferred from a defined set of observable behaviors characteristic of that type of conceptual system.
4. Common information processing strategies are applicable to the utilization of conceptual systems sharing a common structure.
5. Appropriate instruction will produce sizeable transfer of learning across conceptual systems sharing a common structure.

Briefly described, the methodology involves three distinct but inter-related techniques of analysis: <u>content</u>, <u>task</u>, and <u>skills</u>. In content analysis (1) types of conceptual systems characteristic of a discipline or subdiscipline are identified, (2) networks of analytic concepts are formulated, providing a representation of the logical structure for each type of system, and (3) specialized conceptual systems are categorized according to type of network it exemplifies. In task analysis, performance requirements relevant to specific types of conceptual systems are identified. These requirements are stated as input-output relations between analytic concepts in the same network, thus defining tasks by means of their conceptual structure. In skills analysis, effective information processing strategies for the performance of particular tasks are described. These are prescriptions for behavior defined at a psychological level, and provide the basis for planning and predicting transfer among tasks and across content.

The papers presented in this volume are divided into two main sections. Papers in Part I present the theoretical rationale underlying the proposed methods, and describe the procedure for skills analysis. Papers in Part II illustrate applications of content, task, and skill analysis in the science inquiry area at the primary-grade level. Abstracts are appended summarizing additional related papers.

I. Theoretical Orientation

Working Paper 1

THE ROLE OF SKILLS ANALYSIS IN INSTRUCTIONAL DESIGN (TN 2-72-50)

David W. Bessemer and Edward L. Smith

Skills are inferred psychological processes employed in the performance of a task. When performance changes as a result of learning, there is (by definition) a corresponding change in the operation of an underlying skill or system of skills. In recent years, an awareness has been growing among those challenged with the solution of educational problems that a scientific understanding of skills is an important factor in the design and development of improved instructional systems. The capacity to achieve such understandings and to apply them in solving educational problems, however, has yet failed to increase substantially.

The technology of skills analysis remains in an unsystematized state. There is still considerable confusion about how skills should be conceptualized and related to content and tasks in an educational context. There is little agreement on the appropriate level of analysis which should be adopted in the description of skills, nor is there much consensus on the methods which can be used to derive useful and accurate descriptions. Past attempts at skills analysis have employed widely varying methods and levels of description. Several examples of skills analyses illustrating various approaches have been discussed in a recent review by Glaser and Resnick (1972). From these examples, only the haziest sort of image can be formed of the kind of product which can be expected to result from skills analysis and the ways in which the results can be used to improve instructional procedures.

A new approach to skills analysis is presented below. The approach has been formulated in a systematic way which contributes to the resolution of many of the uncertainties which presently surround this sort of enterprise. In the sections which follow, the uses of skills analysis are discussed, and a level of description is selected which may serve to maximize the utility of the results. A method of analysis is presented, and related to content and task analysis. Application of the results is illustrated in relation to the design of instruction to achieve lateral and vertical transfer.

USES OF SKILL ANALYSIS

Skills analysis, as conceived here, results in a description of psychological processes operative during performance of a given task. Such a description constitutes the central component of a theory of performance for that task, and is essential as a foundation for the design of effective instruction involving that task.

There are at least four aspects of instructional design, including specification of 1) outcomes, 2) assessment instruments, 3) sequencing of outcomes, and 4) specification of an instructional procedure for each outcome. The way in which a theory of performance can be used as a basis for deriving such specifications has important implications for what the theory of performance should be able to do, in terms of the kind of inferences which the theory ~~should~~ mediate.

(1) Specification of Outcomes

For a number of years it has been generally recognized that the goals of instruction could not be defined merely as "knowledge" or "understanding" of a certain domain of content (or information) consisting of concepts, facts, relationships, and principles. Such a definition implies that some sort of cognitive representation of the content domain has been acquired, but does not indicate what an individual should be able to do in that domain. Without a specification of the tasks which one should be able to perform, the existence, much less the utility of the cognitive representation cannot be demonstrated.

In reaction to the vagueness of educational goals defined in terms of content, the more recent emphasis has been on behavioral objectives. The originators of this emphasis (Tyler, 1950; Bloom, 1956; Mager, 1962) have been primarily concerned with providing a firm operational basis for evaluation, but such objectives have been used more and more as the basis of planning instructional sequences and strategies.

Written at various levels of detail, behavioral objectives are essentially task specifications. The stimulus conditions in which performance is to be observed is described or at least bounded by implicit limits, and the response or responses which qualify as successful performance are defined. While behavioral objectives are sometimes rightfully criticized as too narrow in scope, or as obscuring the overall organization of content, the value and necessity of defining tasks is now commonly recognized.

Not so commonly recognized, however, is the fact that a variety of educational outcomes can result from instruction on a particular task, even when all students fully master the task. To specify instructional outcomes, some description must be provided of what is learned, or how the observable task performance is carried out. In complete form such a description would state what the underlying skills are, how they operate during task performance, and how they were acquired or reorganized during instruction.

Evidence for diversity of learning in the same task is abundant in psychological research on learning. A considerable portion of research on learning is directed toward analyzing what is learned when a human or animal acquires the ability to perform some task. One of the clearest examples of alternative modes of learning and performance in a simple task comes from research on concept identification learning. One can learn to perform this task either by discovering the classification rule required to correctly sort positive and negative exemplars, or by rote learning stimulus-response associations to each exemplar presented. There is nothing in the original learning data which clearly differentiates these alternative outcomes. However, as Lowenkron (1969) demonstrated, quite different performance results on subsequent reversal tasks, or in classification of new exemplars. The rule learning subjects can correctly classify new exemplars whereas the rote learners cannot. The rule learning subjects reverse rapidly, but the rote learners slowly.

A similar phenomenon shows up in learning-to-learn studies in animals. Both cats and monkeys readily acquire the ability to perform one-trial reversals in a successive position paradigm, the cats being even more rapid learners than the monkeys (Warren, 1966).

Subsequently, the monkey can immediately perform an object discrimination learning set at a high level, whereas the cats respond as if they had received no prior training. This is true also when the successive reversal task is based on object cues, rather than positions, although in that case the monkeys acquire the reversal learning set more rapidly than the cats.

Both of these examples indicate that the supposed operational precision of behavioral objectives is largely illusory. No successful science has yet been built which deals exclusively with directly observable events, and the behavioral sciences will not be the first exception. All sciences find it necessary to postulate unobserved (or unobservable) entities and processes which relate to observables in complex ways. It is true that the job of specifying outcomes in terms of skills will be more difficult, the nature and operation of skills will have to be inferred from indirect evidence. Nevertheless, the gains in realism and power of prediction should make the effort worthwhile.

Recent developments in psychological studies of learning indicate that pure operationism in the style of the 1940's and 1950's is quite dead. All theoretical positions have been augmented by a diverse host of mediational, information processing, or statistical sampling mechanisms which increase both the precision and testability of the theoretical conceptions involved.

In summary then, outcomes must be specified in terms of skills if the generalization or transfer potential of instructional outcomes is to remain under control. Specification of skills requires the development of hypotheses about the skills enabling task performance. Such hypotheses mediate predictions about observable phenomena, which permit indirect verification of the hypotheses.

One common reaction to arguments for specifying outcomes in terms of skills might be that there is little reason to care how the task is performed just so that it is performed. This reaction would be entirely valid if the tasks included all the performances which the instruction was intended to enable. However, education is not provided simply for the purpose of enabling the student to perform the items of a posttest. The whole justification of education is to provide the individual with capabilities which can be used to handle the requirements of various diverse circumstances which the vagaries of life present. Thus, the particular skills which are acquired make a great deal of difference in what kinds of new situations the student will be able to handle.

Presently, it is impossible to anticipate completely what will be required of any individual once he leaves the educational system. This is particularly true when the rapid pace of cultural and technological change is considered. Nevertheless, it should be possible to determine what skills and skill systems have the broadest transfer potential. The "ecological validity" of outcomes could also be investigated empirically, by examination of cultural practices in relation to various disciplines, as well as the projection of future trends in the development of disciplines. The classical emphasis on "understanding" was correct, though incomplete, since it was based on the notion that general cognitive mastery of a system of ideas in a discipline was essential in dealing with novel situations related to that discipline.

(2) <u>Specification of Assessment</u>

This problem is closely related to the first. If a task can be performed in more than one way, then successful performance on items of a particular type representing one task does not indicate how the task was performed. It also becomes very difficult to think realistically in terms of psychometric models in which ability (and items) are arrayed on some continuum from low to high ability (or easy to difficult items). It seems much more realistic to think of variations in performance among students as resulting from different types of learning so that something akin to Lazarfeld's (1959) latent structure model would be more useful.

If the processes underlying performance are conceived of as a complex interacting system of skills, with an overall probability of correct response generated as some function of the probabilities of successful operation of various components, then a quite different view of testing seems in order.

Suppose first that alternative skill systems are postulated as the basis of task performance. In this case, the objective of testing should be to diagnose which system is operative in the individual case. On the other hand, if the operation of a particular skill system has been established, the objective should be to diagnose the effectiveness of the system's functioning.

In either case, a complex series of items seems to be called for, rather than one item type for a particular task. Based on the kinds of hypotheses which were discussed above, the items can be carefully designed to permit inferences to be made concerning whether or not the intended skill outcomes were achieved. Items can be designed to tap various skill components separately or in combination, or designed to manipulate independent variables known to influence skill operation in predictable ways. The inferences would then flow from the pattern of item performance, rather than from artificial quantification of performance levels.

The payoff of a diagnostic approach to testing is obvious. Diagnostic testing would be clearly advantageous in formative evaluation, since it would pinpoint weaknesses in instructional procedures. After development, diagnostic testing is an essential ingredient of individualized instruction. Given the test results, readiness for subsequent instruction can be determined, predictions made of instructional time, and alternative routes or remedial instruction prescribed as the results warrented.

Diagnostic testing may not be practically implementable under present conditions. However, moves in this direction are commonly regarded as desirable and inevitable over the long term, and they would seem to follow naturally from the kind of theoretical conceptions of human performance which should grow from intensive work in skills analysis. Such prospects seem worthy of considerable investigation.

(3) Sequencing of Instruction

A student cannot work on and learn to perform many tasks at the same time. When instruction over the period of a course, unit, or even a lesson is considered, the need for some plan for ordering the sequence of instructional events is obvious. Given a set of tasks which have been chosen as a basis for instruction, the tasks can only be mastered in some order, and presumably, some orders will be better than others in terms of the overall effectiveness and efficiency of instruction.

Most thinking about the sequencing of instruction is based on the task analysis work of Gagné (1970). Following techniques adapted from the development of training in military and industrial settings, a complex behavioral objective is broken down into component performances which are thought to be carried out during the overall complex performance. In some analyses, the components seem to represent the sequence of actual performances which must be carried out in a particular order to perform the complex task. In other analyses many components seem to represent performances which serve as the basis for acquiring other performances involved in the complex task, but which do not actually remain in the final form of performance which is achieved. Either way the task analysis replaces one complex task with a series of other tasks arranged in a hierarchical ordering. In Gagné's view, such a task hierachy can be presumed to lay out the proper order of learning and instruction leading to mastery of the complex task. Although the distinction between tasks and skills (Smith, 1972a) is often overlooked, task hierarchies are generally considered implicit hypotheses about underlying skill structures.

There does not seem to be any real basis for most such hypotheses. If the complex task consists of a sequence of steps which must be carried out in a given order, separate tasks incorporating individual steps can often be taught in a variety of orders. It may be possible to construct the sequence of behavior starting at the beginning, or the end, or even in the middle. Furthermore, each of the steps can themselves be recognized as involving a complex systems of skills, and analysis of the skills for each step provides the critical information needed to devise an appropriate ordering of instruction.

Take, as an example, novel word-decoding based on spelling-sound correspondences rules. This task can be regarded as involving two steps: 1) production of a sounded-out version of the novel word and 2) blending of phonemic components to produce a word with correct pronunciation. Which of these should be taught first? Only analysis of the skills involved in tasks associated with each step and research based on hypotheses generated by such analyses can provide an answer.

Situations in which certain performances serve as a basis for learning other performances seem to be more in line with Gagné's assumption. On a broad scale, it is quite likely that there are unavailable prerequisites for many tasks which are inherent in the nature of the tasks themselves, and which can be easily identified without much argument. Most educators would assume that the ability to perform arithmetical operations necessarily precedes training with their abstract algebraic representations. It can be contended, however, that some skill model is always implicit in such assumptions, and once examined explicitly the prerequisite relations often do not seem so compelling.

Classification, for example, is based on a class rule involving the values of criterial variables. Thus one might easily suppose that the ability to describe elements in terms of values for those variables is prerequisite to classification. Yet, it is well known that the ability to classify can be taught, and is learned for many classes, long before description tasks based on variables and values can be performed. The acquisition of value labels and the communication of a class rule often seems to follow on the heels of classification learning itself. Detailed study of the skills involved should reveal which order of instruction is likely to prove more advantageous.

A major defect of the Gagné approach is that it focuses so much on the particular behavioral objectives in hand that it tends to obscure and fractionate the relationship among tasks which involve similar skills, even though the tasks appear quite different. Given a series of objectives for reading, one is not likely to consider how these tasks relate to those of spelling since the S-R relationships are essentially reversed in the two cases. However, when one examines the underlying skills involved in reading and spelling, a considerable communality in skills is discovered which suggests that they should be taught together in some fashion, rather than separately or in some fixed order. When a word is spelled, the situation for word readings is inherently created. Certainly, much accuracy in spelling comes from the fact that mispellings which create unreadable nonwords will immediately be recognized as incorrect.

The primary criteria which can be adopted for the design of sequences of instruction are that 1) the skills required to perform certain extra-school tasks are provided in a timely fashion in relation to the demands which the culture places on the student, and 2) the positive transfer potential to subsequent instruction is maximized while the negative transfer potential is minimized. As was pointed out in the discussion of outcomes above, detailed skill description is a key ingredent of any attempt to understand the utilization and transfer of learning, and in the design of instruction controlling these phenomena.

Much empirical information on both the "ecological validity" of skills, and principles of skill application and transfer will be needed to follow such criteria. Detailed skills analysis work promises to lead toward such information in a way which hierarchical task analysis by itself cannot. Later sections of the paper deal with the problems of application and transfer in greater detail.

(4) <u>Specification of Instructional Strategies</u>

Instructional strategies are based on knowledge of the events and conditions which produce effective learning. Current recommendations about instructional strategies are largely based on task taxonomies. That is, various types of tasks are recognized, each of which is supposed involve a different kind of learning and to require somewhat different events and conditions for that learning to take place efficiently. Gagné (1970), for example has identified eight basic types of learning, and has presented principles of instruction applicable to each.

The recommendation is then made that tasks which define the objectives of instruction be identified according to the type of learning involved, and an instruction strategy be designed based on the principles for that type.

The problem is that since most tasks involve a complex system of skills, many kinds of learning are involved in the mastery of a particular task. Consider again the sounding-out task mentioned above. A detailed analysis of skills involved in this task (the presentation of which the reader will be spared) suggests that at least four, and perhaps more of the types of learning recognized by Gagné are involved in mastering this task.

The design of instructional strategies must start from a description of the skill system available at the beginning of instruction, the skill system to be reached, and knowledge of the way in which experiences and practice modify skills or reorganize skill systems. Then a series of instructional events and practice requirements can be devised to move the initial skill system through a series of stages to reach the desired outcome stage.

It should be clear that the nature of the outcome dictates this process, while the task does not. Given a particular concept identification task, one could design instruction to produce either rote learned associations between the particular stimuli used and the responses, or to produce learning of a rule which would enable any stimulus to be classified. Which should be done can only be based on a decision that one or the other result is desired.

There is a great deal of psychological literature available on the nature of learning in many kinds of laboratory tasks. It has been very difficult to apply the results of this literature in designing instructional strategies since the tasks involved in instruction are so unlike the standardized laboratory tasks. Task analysis alone cannot insure that the correct analogy has been drawn between a laboratory task and the behavioral objective at issue. Yet the performance of either draws upon some types of complex human performance skills possessed by every individual. When both laboratory tasks and tasks selected for instruction are understood in terms of skills, then the way in which the results of psychological research can be applied is easily seen. If paired-associate learning involves skills in cue selection, storage, retrieval, and response integration, then variables which influence these skills in various ways as discovered in research on paired-associate learning can be managed for facilitating effects in whatever educational task involves these same types of skills.

DEFINING AND ANALYZING SKILLS

Various tactics have been adopted by psychologists and educators as a means of defining skills. In many cases the distinction between skills and task performance is not maintained, a skill simply being the ability to perform some task. A slightly more sophisticated approach defines skills indirectly in terms of tasks, as the mechanisms which underly the ability to perform a given task, without bothering to get more specific. Correlations of performance on different tasks is often used to infer the presence of common skills.

When more limited interests in performance are involved, particular characteristics of task stimuli or responses may be used to define skills. When the stimulus features of a task are held constant, or implicitly understood, a response-based definition is likely. When the response features are constant or understood, stimulus features may be used. Similarities in the stimulus or response features of tasks are often used to infer the presence of common skills.

Another course is to define skills indirectly in terms of the conditions or variables which influence learning or performance on one or more tasks. When a particular variable influences performance on several tasks in a similar fashion, the tasks often may be inferred to involve a common skill or skills.

As the prior discussion suggested, all methods of defining skills in terms of tasks, or directly in terms of task performance are unsatisfactory. The only satisfactory way of dealing with unobservable entities is to postulate the existance of some mechanisms, assign properties to the mechanisms including some systematic connections to observables, deduce observable consequences, and check out the validity of the predictions in one way or another. This method has become increasingly dominant in psychological theory, and is the one adopted here. Thus, all the skills will be defined as covert, unobservable mechanisms having some indirect relation to observables.

A later paper will develop the method of skill analysis in much greater detail so that only a brief sketch will be presented here. The specific method grows out of very general assumptions about the nature of human performance and skills.

As a general working hypothesis, it is assumed that all task performances are mediated by an information processing system. The information is in the form of codes (representations, schema, concept images, or any other words you like) and processing is carried out by means of various kinds of operations which transform one code into another. A skill is defined jointly by the input and output codes, and the operation performing the transform action. Operations may also be coded, so that some skills transform operational codes, as well.

Four general areas of skills are recognized, as illustrated in Figure 1. Skills in these areas form the processing system interposing between stimulus and response in any task. First, there are input skills which receive external stimuli and transform them into coded substitutes which are amenable to further processing. Second, there are processing skills which go through the various operations required to get from the stimulus codes to response codes which are required by the task. Third, there are output skills, which convert response codes to observable behavior. Finally there are control skills, which transform operational codes, and act to regulate the sequencing and organization of the other three types. Also listed in the Figure are some common psychological terms used to refer to the kinds of skills involved.

The question remains of how to use this machinery to generate a description of skills involved in performing a task. It is assumed that there are (or can be) codes for every relevant feature of the stimulus situation. Additional codes are derived as needed from

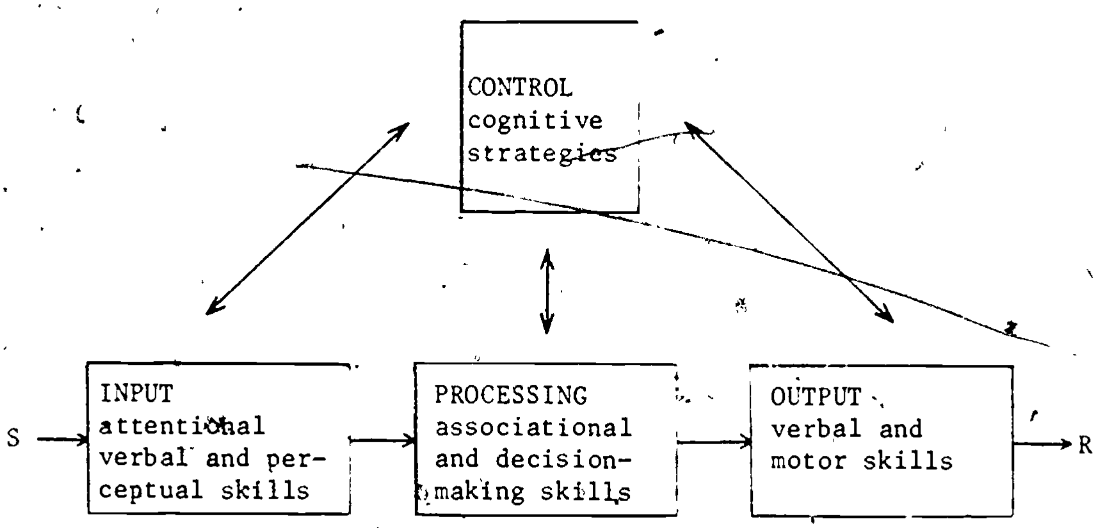

Fig. 1. General skill areas assumed to be involved in any task performance.

memory, assuming that the relevant past experiences have caused the codes to have been stored. Note that the codes available to the system are controllable by manipulation either of the current environment or past experience.

It is further assumed that all codes are potentially connectable by some operations, if relevant training is given to establish the connections. Then given the codes and their potential connections, a plausible pathway is selected to carry from stimulus codes to response codes. This pathway identifies a control program (or strategy) for the skill system involved in performance. On examining the connections between codes, plausible forms of operations to perform the transformations can be postulated based on current theoretical conceptions of processes underlying behavior. The result is a description of a possible sequence of steps carried out to perform the task, where each step is identified in terms of an operation and the codes which serve as input and output in the step.

Such performance strategies and skill descriptions are not intended to be realistic descriptions of the way in which tasks are actually performed given any current instruction, although various ideas about how tasks are performed may enter into their formulation. The analyses are intended to produce descriptions of potentially trainable outcomes, which will be descriptive of performance if instruction can be successfully designed to achieve such outcomes. If the availability of codes and the nature of connections are controllable through instruction, then the outcomes should be feasible.

In such an approach, many alternative skill systems can be proposed within the limitations of the task definition. The relative merit of alternatives remains as a matter for judgment, research, and results of development and evaluation to decide. At present, the main objective is to arrive at skill descriptions which meet the need of instructional design, as they were outlined in a prior section.

The present approach is prescriptive, rather than descriptive, following the suggestion of Bruner (1966). Once such outcome prescriptions are combined with systematic principles successfully dealing with the problems of instructional design, a theory of instruction of the kind which Bruner proposed will have been developed.

RELATION TO CONTENT AND TASK ANALYSIS

The applicability and generality of processes and strategies depend on the structure of the relevant conceptual systems and the overt performance requirements to be made on the individual. Thus, the specifications for domains for skills analyses should reflect these two aspects of potential instructional outcomes. The specification of these aspects are primary purposes of content analysis and task analysis, respectively. While content analysis identifies and describes the kinds of conceptual systems represented by the knowledge of various disciplines and subdisciplines, task analysis identifies and describes the performance requirements relevant to a given kind of conceptual system.

Without sufficiently broad content and task analysis, there is no basis for determining the applicability and generality of proposed processes and strategies. Furthermore, broad content and task analyses may be suggestive of general strategies whose utility would not be evident from a narrower point-of-view. Analysis in the context of isolated conceptual units or tasks might result in strategies which will not be useful for other tasks or when additional conceptual units are involved. Attention to conceptual systems and sets of related tasks facilitates the identification of comprehensive strategies and insures that lower level strategies will be compatible with them.

Another reason for the strong emphasis on content and task analyses as a basis for skills analysis is the relatively large amount of resources required for skills analysis. Careful selection of the domain for skills analysis is required to enhance the probability of payoff without enormous expenditure of resources.

Procedures developed for content analysis (Smith, 1972b, 1972c; Smith & McClain, 1972; McClain, 1972) involve the identification of the specialized or systemic concepts of a discipline (e.g., weight, 32 pounds, carnivore) and their classification as examples of various analytic concepts (e.g., variable name, value, and class name). The logical structure of many networks of systemic concepts can then be represented by a few networks of analytic concepts. This structure influences the performance requirements which should be placed on the learner as well as how these requirements can be fulfilled.

A selected analytic network provides a focal point for task analysis (Smith, 1972c). Potentially important performance requirements appropriate for an analytic network can be described free of systemic content.

Tasks defined in this manner specify the logical operations required, but not the skills with which those operations can be carried out. A set of important tasks for a broadly applicable analytic network provides an appropriate focal point for skills analysis. For example, an analytic network frequently found illustrated in primary science curricula is the variable-value network. This network is exemplified by systemic networks such as those associated with weight, length, temperature, color, etc. A number of description, comparison, seriation and sorting tasks have been identified as important competencies for such networks. Skills analysis identifies processes and strategies by which such tasks can be carried out. Strategies and processes found applicable to many tasks across a variety of these systemic networks can then be selected for development in instruction.

CURRICULUM AREAS AND TYPES OF TRANSFER

In their recent handbook on techniques of evaluation, Bloom, et al., (1971), recommended that the educational objectives for a curriculum area be represented by a two-way matrix, with types of tasks represented along one dimension, and areas of content along the other dimension. The cells of this matrix then represent particular kinds of objectives, (i.e., task performance in relation to content), and can be used as a basis for defining item formats.

The techniques of content and task analysis briefly described above enable such matrices to be prepared to represent a curriculum area with much greater precision than has previously been the case.

The proposed techniques suggest that a curriculum area can be represented by several such matrices, one matrix for each analytic network. The columns of the matrix represent an inventory of the systemic networks which exemplify the analytic network, and the rows comprise an inventory of tasks defined in terms of analytic concepts.

So far, skills analysis has been discussed only in relation to tasks without regard to what systemic content the task might be applied to. It should be made clear that with each new set of systemic content, there will be content-specific skills to be acquired. The implicit assumption has been, however, that strategies and additional processing skills can be identified which will apply to all systemic networks subsumable under an analytic network. Viewed in the context of a task-content matrix, it can be seen that this extreme assumption is probably faulty, at least to some degree. Certainly, there are special characteristics of some systemic networks which will require special adaptation of the strategies and general processing skills. At the other extreme, too many such adaptations would make the notion of generally applicable strategies and processing skills meaningless. It seems reasonable to assume that the actual case lies somewhere in between, that is, that strategies and processing skills applicable across some range will extend across entire curriculum areas for many skills and even further for some.

One main implication of curriculum representation by task-content matrices is that training on a variety of tasks with a variety of content is highly desirable. Furthermore, since training undoubtedly cannot be conducted in relation to every cell of the matrix, special provisions for transfer or generalization of skills and strategies are required so that the results of training do in fact, have broad applicability.

As has been indicated in the prior sections on the specification of outcomes and instructional sequences, the primary contribution of skills analysis to instructional design is the basis it makes for the management of transfer. Two kinds of transfer can be distinguished which are related to the dimensions of task-content matrices. Lateral transfer is the effect of learning to perform a task with one kind of systemic content on the later learning of that same task with other systemic content. That is, lateral transfer is transfer of learning across the rows of a task-content matrix. Vertical transfer is the effect of learning to perform one task with certain systemic content on the later learning for a different (generally more complex) task for the same systemic network. That is, vertical transfer occurs between cells in the same column of a task-content matrix.

In general, vertical transfer results from the acquisition of systemic procedures and concepts (i.e., the acquisition of skills with specific input and output codes). Lateral transfer, on the other hand, results from the acquisition of analytic concepts and procedures, (i.e., the abstraction and generalization of the strategy or control program for a given task). The sections which follow discuss in detail phenomena of lateral and vertical transfer and the design of instructional sequences to facilitate transfer. The views on transfer of the present paper derive from work on learning sets in the case of lateral transfer, and from work on learning hierarchies in the case of vertical transfer.

VERTICAL TRANSFER AND LEARNING HIERARCHIES

A learning hierarchy is a sequenced set of learning events by which a relatively complex skill system can be acquired step by step (Gagné, 1968; Smith, 1972a). The primary consideration in the design of such a hierarchy is the achievement of substantial positive transfer from one learning event to the next. The mechanism for such transfer is the acquisition of specific skills with particular input and output codes. Once acquired in the context of relatively simple tasks, the skills are potentially available for utilization in the performance of more complex tasks. The contribution of skills analysis to the design process is, first of all, to identify skill systems with which important tasks can be carried out. Secondly, it provides a basis for identifying tasks which can be carried out with smaller components of those systems and can therefore serve as enroute learning steps. If the skills analysis is adequate and appropriate instructional procedures are employed, mastery of enroute outcomes should develop skill components required for higher level outcomes. This in turn should greatly facilitate the attainment of those outcomes. That is, mastering all the outcomes in the hierarchy in order should require less time and/or result in higher levels of mastery than had the students simply practiced items for the terminal outcomes themselves.

Skills analysis conducted on the basis of prior content and task analyses allows hierarchical relations to be defined between tasks, free of systemic content. Such relations are expected to hold across many of the systemic networks exemplifying the analytic network in terms of which the tasks are defined.

The hierarchical relationship and the role played by skills analysis in its explication are illustrated by the following examples. Figure 2 presents a strategy and hypothesized processes for performing a directed description task. In this task, the individual is presented with an element and the name of the variable on which it is to be observed and described. A value describing the element on the named variable is required. The strategy defined for this task involves matching the element to one of a set of standards labeled with corresponding values. The strategy consists of a sequence of processing steps and decision points. The processing steps are defined in terms of input and output codes. They represent either primary processes, taken as primative functional units, or secondary processes, themselves defined in terms of primary processes. Several primary processes are involved in the strategy illustrated in Figure 2, including <u>interpret</u>, <u>find</u>, <u>notice</u> and <u>compare</u>. The secondary process <u>observe</u> is involved a number of times. Many primary processes represent fundamental processes similar to those studied by psychologists. Others represent more complex behavioral sequences which, because of their common occurrence in the everyday behavior of children may not need to be further analyzed.

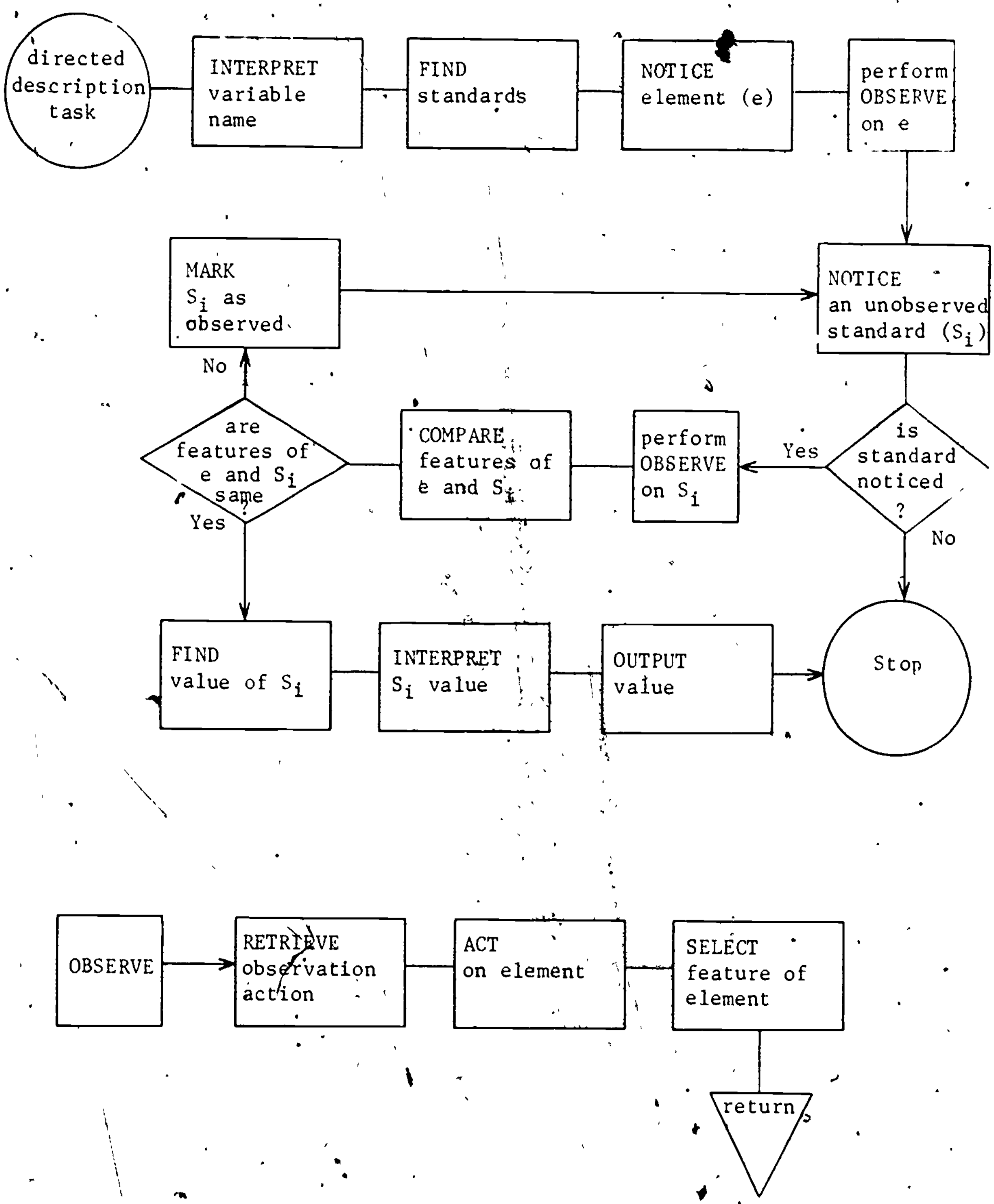

Figure 2. Strategy and processing steps for the directed description task including the OBSERVE subroutine.

Figure 3 presents a similar analysis of a directed comparison task. In this task the individual is provided with two elements and the name of the variable on which they are to be compared. The requirement is a report as to whether or not the two elements are the same on the named variable. The strategy involves a comparison of the appropriate perceptual features of the elements. The skills analyses for these two tasks indicate considerable similarity in the processing skills required for a given set of systemic content. The directed comparison task involves the interpret, act, select and compare primary processes, and the observe secondary process in much the same way as the directed description task. However, the description task strategy involves obtaining an appropriate set of standards (find), multiple applications of the observe process, and the application of interpret and report to a value, none of which are involved in the directed comparison task strategy. The strategy for the comparison task also has fewer steps and fewer decision points, and may therefore characterized as less complex.

The similarity between these two strategies is clear. The decision concerning which should be lower in the hierarchy seems reasonably clear. A complicating factor is the requirement of a verbal response of "same" or "not the name" found only in the comparison task. However, this step does not seem complex enough to outweigh the unique requirements noted for the description task strategy. Such judgements about the relative complexity involved in the unique requirements for a pair of tasks will be required in almost all cases. The reason for this is that some alternative means

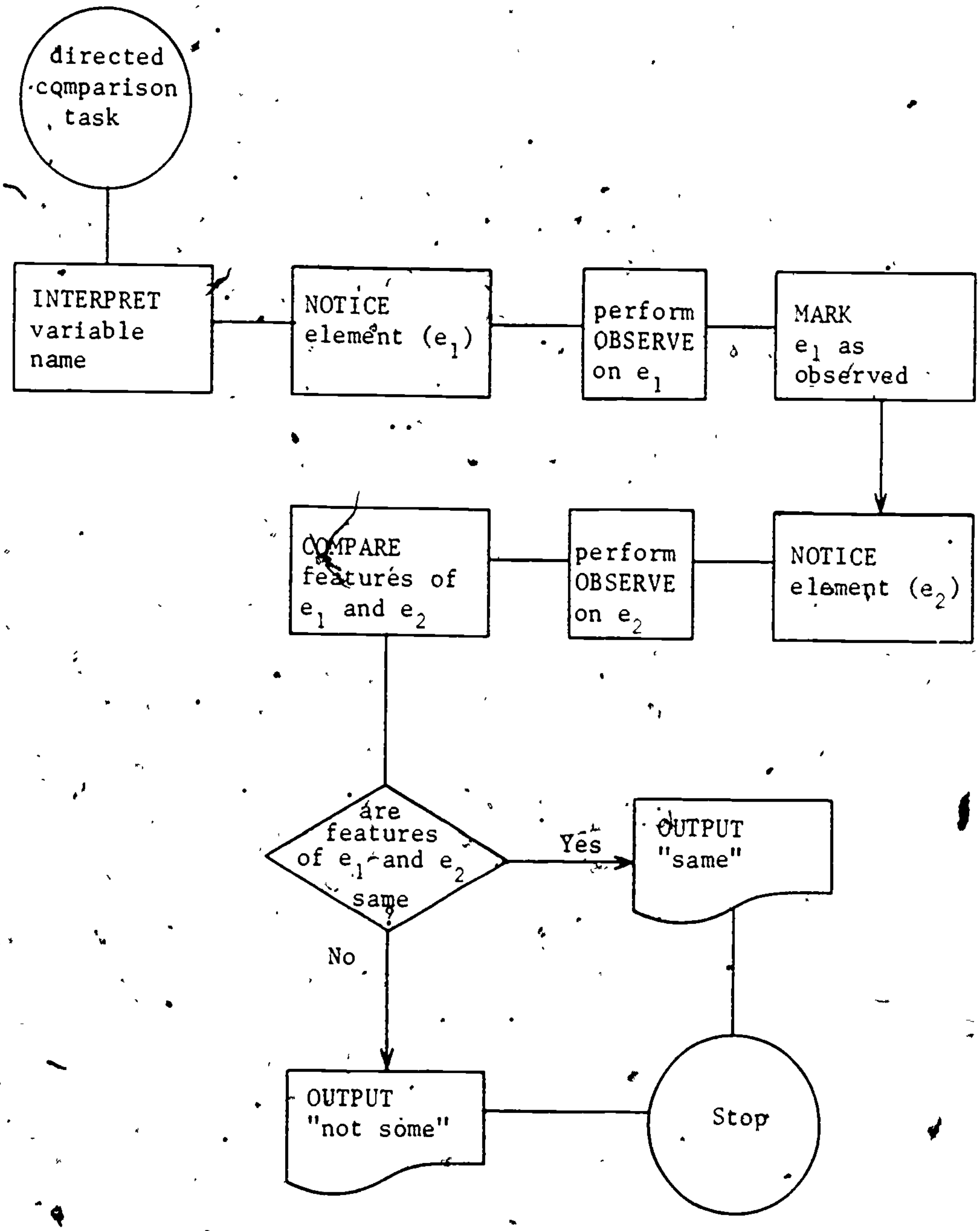

Figure 3. Strategy and processing steps for the directed comparison task.

of obtaining the needed input and providing evidence for the output of a skill component must be included to make up a task to serve as a vehicle for that skill component. Thus, a perfect hierarchy where each task involves only a subset of the skill components of the next higher level task is, in practice, an unrealizable ideal. However, this does not imply that hierarchical sequencing of outcomes based on shared skill components is not possible or useful as an approach to instructional design.

The en-route outcomes in a learning hierarchy are typically less complex than the terminal outcomes, that is, they involve only some of the skill components required for the terminal outcomes and few additional ones. One exception is an "en-route" outcome which is itself an important outcome of equal complexity, but which shares skill components with the "terminal" outcomes. The ordering of the two outcomes may be arbitrary, but the potential for positive transfer should not be ignored.

The transfer effects anticipated on the basis of common skill structures such as those described above apply <u>within</u> a domain of systemic content. However, different systemic networks exemplifying the same analytic network share common features of logical structure. It is therefore assumed that learning hierarchies can be designed so that the same en-route tasks are used for a variety of parallel systemic networks. This assumption is reflected in the above examples where the skill analysis was described at the analytic rather than the systemic level. Thus, the learning set acquisition view of lateral transfer can be thought of as applying to parallel learning hierarchies as well as to (individual) parallel tasks. It is not assumed, however, that one kind of hierarchy will be applicable to <u>all</u> systemic networks exemplifying a given analytic network. Further distinctions between classes of systemic content will almost certainly be required for purposes of learning hierarchy design.

One further possible extension of the present approach which can be envisioned, but which is not treated here involves mastery of a task domain. Following the procedures for content and task analysis which have been developed, it is theoretically possible to prepare an exhaustive inventory of tasks in a domain relevant to a given content area. If all tasks in the domain are subjected to skills analysis, it is similarly possible to inventory all relevant skills and skills systems.

It would certainly be impossible to directly teach all skills systems to ensure the mastery of all tasks for all content. However, it may be possible to insure that a sufficient variety of tasks are practiced to insure that all skill components are acquired. Furthermore, it may be possible to identify strategies for skill recombination and reorganization which would ensure rapid mastery of any new task in the domain which might arise. Thus strategies might be devised to promote vertical transfer as well as lateral transfer.

This conception goes well beyond that of Gagné's learning hierarchies. Aiming the skills analysis at a small number of selected terminal tasks barely scratches the surface of the potential for the management of transfer which flows from the systematic relations among content, tasks, and skills involved in the approach which has been presented here.

LATERAL TRANSFER AND LEARNING SETS

When humans or animals are given a large number of learning tasks of the same type but differing in content, more often than not rapidity of learning each new task increases substantially as successive tasks are mastered. This progressive improvement in rate of learning has been termed "learning-how-to-learn," and the ability formed to learn a new task rapidly has been called a "learning-set."

The outstanding example of learning-to-learn in animals is the object-discrimination learning set demonstrated by Harlow (1949). When rhesus monkeys are given a large number of two-choice object discrimination problems, each presented for a small constant number of trials, the rate of learning each problem improves gradually. After 400-500 problems most monkeys show performance well above the 90% level of correct responding on the second trial, whereas they may only have performed at the 50%-60% level originally on that trial. Acquisition of a learning set has converted a slow, laborious learning process into one which is essentially complete after the initial trial which gives the animal the necessary information as to whether or not the object first chosen does or does not hide the reward placed in a food well below the object.

Similar cumulative positive transfer has been observed in many of the standard human learning paradigms. Probably the best understood case of learning-to-learn in humans is conceptual rule learning in the concept identification paradigm. Initially, there are wide differences in difficulty between concept-identification problems having different conceptual rules (Haygood & Bourne, 1965). Affirmational rule problems are easiest, with conjunctive, disjunctive, conditional, and biconditional rules being increasingly difficult in that order. After many problems have been learned with different relevant dimensions but the same rule, the rate of learning each of these types of problems improves. Ultimately, sufficient improvement accrues until subjects are learning them in a minimal number of trials, the limit determined by the minimal amount of information required to identify the concept. The differences in difficulty have been eliminated between the various rule types.

The mechanisms which are involved in learning-to-learn phenomena are only beginning to be understood. Yet in every case which has been intensively studied, the explanation for marked cumulative transfer seems to involve the acquisition of an information processing and learning strategy which enables successful performance on each new problem with little, if any, new learning required to handle the new content. That is, the relevant information about the new content is gathered efficiently and used in a short-term fashion, avoiding the laborious and slow rote learning of S-R associations characteristic of the inexperienced learner.

Initially, rhesus monkeys learn discrimination problems about the same way as any other animal, by acquiring approach or avoidance tendencies toward the objects as a result of reinforcement and non-reinforcement. The experienced rhesus monkey, however, follows a win-stay, lose-shift strategy with respect to objects (Levine, 1970). On the first trial some stimulus features of the object chosen on that trial are stored, together with information about whether reward ("win" or "lose") occurred or not. On the second trial and later trials, this information serves as a complex cue for response selection based on the rule "If 'win,' on previous trials, stay with same object on next trial; if 'lose,' shift to other object." The fact that this is a short term performance process, rather than more rapid rote-learning is evidenced by the fact that within one hour of training the learning-set trained animal remembers little more about the correct object than an inexperienced animal, despite the much higher level of performance reached (Bessemer & Stollnitz, 1971). Evidence that the reward has a cue function rather than a rewarding one on the first trial comes from experiments on object alternation-learning set, which require a win-shift, lose-stay strategy just opposite to the normal one. Monkeys learn-how-to-learn such problems quite readily. That monkeys can learn to respond consistently to the object other than the one rewarded on the first trial is a finding difficult to reconcile with any traditional reinforcement theory.

In the case of conceptual rule learning, the subject comes to adopt what has been called a truth table strategy (Haygood & Bourne, 1965). The exemplars can be identified as belonging to one of four subclasses based on combinations of values for the relevant dimension. It only remains to determine which subclasses go with which responses. This can be done after one or two exemplars are known. The inexperienced subject however, very likely begins by learning specific S-R associations for a considerable number of particular exemplars before abstraction and generalization occur permitting a general classification rule to be discovered for that new content.

Before learning-to-learn can occur, the learning problems which are presented must have a common structure which permits a common strategy to be utilized. Another requirement is that a large number of content examples must be available to provide sufficient experience with that type of task structure so that a correct strategy can be learned.

The procedures for content and task analysis in disciplines were designed to establish task paradigms meeting these conditions. Content is classified and organized according to analytic networks so that a large number of systemic networks are available involving parallel conceptual structure. At the particular level, sets of materials can be constructed to exemplify each systemic network. Each set of materials can be used along with all of the types of tasks to establish learning-to-learn paradigms as a basis for empirical research on learning sets with realistic school-subject content. This situation is analogous to having a large number of pairs of objects, and various types of problems based on the use of pairs of objects, or having a large number of sets of stimulus patterns using different relevant variables, which can be used with a variety of conceptual rules.

Having established task paradigms and parallel content, it would then be possible to conduct a number of studies of learning-to-learn to uncover and describe the kinds of learning and performance strategies which emerge in such paradigms, and which represent the learning sets which have developed. This is a basic research route which over the long term would permit one to select an effective strategy and design explicit instructional procedures to ensure that all children would acquire such a strategy for each type of task and conceptual system involved in the relevant educational settings.

A basic research approach, however, would be very time-consuming and expensive, given the large number of possible tasks associated with each analytic network. Furthermore, children's strategies may not be the most efficient or broadly applicable. An alternative is to employ a prescriptive rather than a descriptive approach to the analysis of skills which are involved in the learning and performance strategies.

The present assumption is that the strategies, or control programs which regulate learning and performance for a particular type of task, can be directly taught given that the specific skills that they regulate have been acquired. That is, once the conceptual codes which form the input and output of processing skills have been acquired, and the ability to perform the operations is available, a learning and performance strategy can be organized and acquired in the course of learning how to perform a certain type of task. Presumably, training of this kind with several systemic networks would be required for the full development and complete acquisition of the strategy. In subsequent encounters with that task and new systemic content, the strategy will mediate lateral transfer once the relevant codes and the content-specific skills involved in the task have been acquired.

The entire sequence of instruction relevant to an analytic network can be envisioned something as follows. First, the concepts of a systemic network are acquired and simple tasks involving basic skills for that network are learned. Mastery of these skills facilitates the subsequent learning of more complex en-route tasks in a learning hierarchy. The strategies that the children are taught to use in these tasks build up the strategies for the terminal tasks which have been selected. This process is then repeated for another systemic network exemplifying the same analytic network. The specific skills required for the new systemic network are acquired, but the same general strategies are taught as the children master the task hierarchy with the new content. This cycle is repeated for many new systemic networks. Facilitation of learning is likely to result as the child abstracts the strategy from the repeated systemic examples. This will probably allow considerable abbreviation of the task hierarchy for the later examples. It may ultimately permit terminal task performance to follow immediately the acquisition of the new systemic concepts and the basic skills for those concepts.

Consider as an example the variable-value analytic network. Acquisition of a learning set for a task such as directed comparison does not mean that one can perform this task immediately with <u>any</u> variable. After the strategy for directed description has been acquired, but before it can be applied to a new variable-value system, the concepts of the new variable, the values, and the steps of the new measurement or observation procedure must be learned. Once skills based on these concepts have been acquired, and the basic operations which form the steps of the strategy can be carried out, the components are available which permit the strategy to run off to successful task completion.

The introduction of analytic concept labels may enhance the lateral transfer effects of the acquisition of a strategy for important tasks. For example, the introduction of "temperature" as "a new variable" signals that it has something in common with previously encountered variables, and may thus mediate the application of the strategy. The availability of analytic concept labels also make it practical to present general verbal descriptions of the strategies themselves. Of course, it remains to be seen at what level such devices may be successfully introduced.

Analytic concepts and their labels permit the definition of analytic skills and strategies which are probably the substance of very general and powerful inquiry skill. If a conceptual system representing the variable-value network and the class member network have been acquired, for example, a student presented with an unfamiliar classification of elements may acquire a strategy for discovering relevant variables and the class definition. In general, when the student is capable of identifying what network is relevant from given components, he can be taught to inquire into the nature of the missing components.

CONCLUSION

A major goal of the Conceptual Skills Activity is the identification of an interdisciplinary core of conceptual-semantic complexes which can serve to mediate the subsequent acquisition of more specialized complexes. Another, closely related goal is the specification of instructional systems which insure that this interdisciplinary core is acquired and utilized in the course of further instruction. The initial approach to achievement of these goals envisioned a sequence of steps including a general specification of the K-6 curriculum content and organization, a comprehensive identification of specialized conceptual complexes, and finally the complete identification of a common interdisciplinary base of core concepts. The present paper fleshes out this strategy and, in the process, suggests that a good approximation of this base core may be identified prior to completion of the comprehensive analysis originally envisioned.

Content analysis of a subject matter area as described briefly above results not only in a listing of the specialized concepts involved, but also in characterization of the structure of the conceptual systems involved. It appears that a relatively small number of different types of conceptual system are involved in a subject matter area, and that similar types of systems recur in several areas. A particular type of conceptual system, represented by a general paradigm or analytic network, can then serve as a focal point for task analysis and skills analysis. Only a sample of representative specialized conceptual systems or systemic networks need be available for conducting the task and skills analyses and for carrying out empirical studies.

The view of curricular content as sets of specialized examples of a small number of analytic networks led to the selection of a learning set acquisition view of the mechanisms mediating subsequent learning of other specialized conceptual systems. The identification of a set of tasks appropriate to any specialized example of an analytic network defines a set of parallel learning problems. Skills analysis of the sort described above is required to identify strategies and processing skills by which the tasks can be carried out. The inter-disciplinary core concepts which mediate the subsequent learning of specialized concepts are, thus, the analytic concepts gradually formed as the learner acquires a sampling of systemic examples.

The present approach to skills analysis is unique, not only by virtue of its close relationship to subject-matter content, but also in the extent to which it reaches out to the unmapped frontiers of psychological research on cognitive processes. The specific mode of skill representation in terms of information processing steps and strategies is admittedly speculative and open to revision or even abandonment if experience proves it unproductive. The promise of the approach requires considerable evaluation in well-controlled experimental research designed to produce the kinds of transfer effects which are anticipated. In addition, the practical consequences of following such a procedure should be examined in attempts to design and develop instructional protocols in realistic subject-matter contexts.

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Working Paper 2

AN INFORMATION PROCESSING APPROACH TO SKILLS ANALYSIS (TN 2-72-49)

Janis McClain and Edward L. Smith

In an effort to establish an appropriate framework for the design of science instruction, Smith (1972) has identified several networks of interrelated analytic concepts. These analytic networks represent abstractions of the structure of specialized conceptual systems characteristic of a discipline. Each network is associated with a set of tasks generated from the components of the network (i.e., the analytic concepts). Tasks, or performance requirements described in terms of observable inputs and outputs, are differentiated from the hypothetical skills which underlie performance of the task. Shared underlying skills reveal the behavioral relations between tasks and allow predictions of transfer between tasks; if a skill or group of skills is involved in each of two tasks, the learning of one task should facilitate the learning of the other. Thus, for a given task domain, the identification of skill substructures is useful for designing instruction with task arrangements promoting transfer. Once skills are identified, it is possible to choose en-route tasks and sequence instruction so that early tasks have skill components which are involved in later and more complex tasks (Bessemer & Smith, 1972).

The present paper discusses an information processing method for identifying skills and illustrates the application of this method to selected tasks important in the primary science curriculum. This approach, analogous to that utilized in computer programming, enables one to identify processing mechanisms which are sufficient for successful task performance. A task routine is prepared consisting of a sequence of processing steps and decision points. Each processing step is either a primary process, taken as a primitive functional unit defined in terms of input-output relations, or a secondary process, itself defined in terms of primary processes. Many primary processes are closely related to fundamental processes studied by psychologists. As such, they represent plausible hypotheses based on current psychological knowledge. Others may represent more complex behavioral sequences which, because of their common occurrences in the everyday life of children, need not be further analyzed, at least for the purposes of the present paper.

The actual preparation of the processing routines takes place in two stages. In the first phase, preliminary routines are designed which specify the strategy and the general nature of the processing steps. Several examples of such routines are described in the paper. Many decisions about the adequacy of strategies can be made at this level, including the applicability of the strategy to a content domain. Once such criteria have been fulfilled, a second phase of analysis is entered in which the processing steps are given a psychological interpretation. This phase is illustrated in the last section of the paper.

The tasks selected to illustrate the skills analysis approach are associated with the variable-value analytic network. This network involves the entities which are the objects of study in a given discipline and the characteristics or properties used in studying them. The principal components of this network are:

elements -	the entities (e.g., objects, events, constructs, symbols, etc.)
variables -	the characteristics or properties of elements (e.g., weight, color) which are used to describe or otherwise study elements
values -	the terms assigned to elements for a given variable (e.g., rectangular, red)
observation/measurement - procedure	that procedure which, for a given variable, results in the extraction of value information about an element.

For this network four types of tasks have been identified: description, comparison, seriation, and sorting (or single variable classification) tasks. For each task type, terminal or outcome tasks have been identified. The three description outcome tasks have been selected for the present illustration.

Table 1 (taken from Smith, 1972) summarizes the three description outcome tasks in terms of given and required components and illustrates each task with a sample item. For some routines, blocks of several steps have been differentiated from other steps and grouped together as subroutines. These may recur in routines for several different tasks. Figures 1-5 diagram processes involved in the description routines and subroutines. As will be discussed later, the specific processing steps involved in a given task are influenced by the kinds of systemic and particular content of that task. The routines diagrammed here are appropriate for discrete object elements and

TABLE 1

SIMPLE DESCRIPTION TASKS

Task Name	Given Input	Required Output	Sample Item
Element Identification	a set of elements a value for a variable	an observation/measurement procedure for the variable an element described by the given value	Given samples of salt, sugar, flour, sand, and chalk. "Which substance is soluble in water?"
Directed Description	an element a variable name	an observation/measurement procedure for the named variable a value for the named variable which describes the given element	Given a mineral specimen. "Determine and report the hardness of this rock."
Nondirected Description	an element	an observation/measurement procedure for a variable a value describing the given element on that variable (multiple cycles may be required)	Given a leaf specimen. "Describe this leaf as completely as you can."

qualitative variables for which the relevant features can be obtained through simple perceptual observation.

PROCESSING ROUTINES FOR DESCRIPTION OUTCOME TASKS

The nondirected description task, represented by the item shell, "Describe this object in as many ways as you can," requires an exhaustive description of the object in terms of variables whose choice and number are determined by the child. An overview of the processing steps involved in this task is diagrammed in Figure 1. Two subroutines are identified whose steps are diagrammed in Figures 2 and 3. In brief, the nondirected description task routine requires recall of a variable and its observation/measurement procedure from memory, and the subsequent execution of the procedure and reporting of obtained results. These latter subroutines involve the identification of standards with which the element may be compared. These standards may either be recalled or be available in the environment of the child as, for example, in a classroom situation where color samples are displayed (see Figure 2). For qualitative variables the child must compare the element to each standard until a matching standard and its value are identified (Figure 2). In the nondirected description task, the only given component is the element. The child must supply from memory the variable, value and observation/measurement procedure. Furthermore he must repeat the routine until his supply of applicable variables is depleted (Figure 1).

The directed description task (see Figure 4, and subroutines of Figures 2 and 3) represented by the item shell, "Describe the (variable

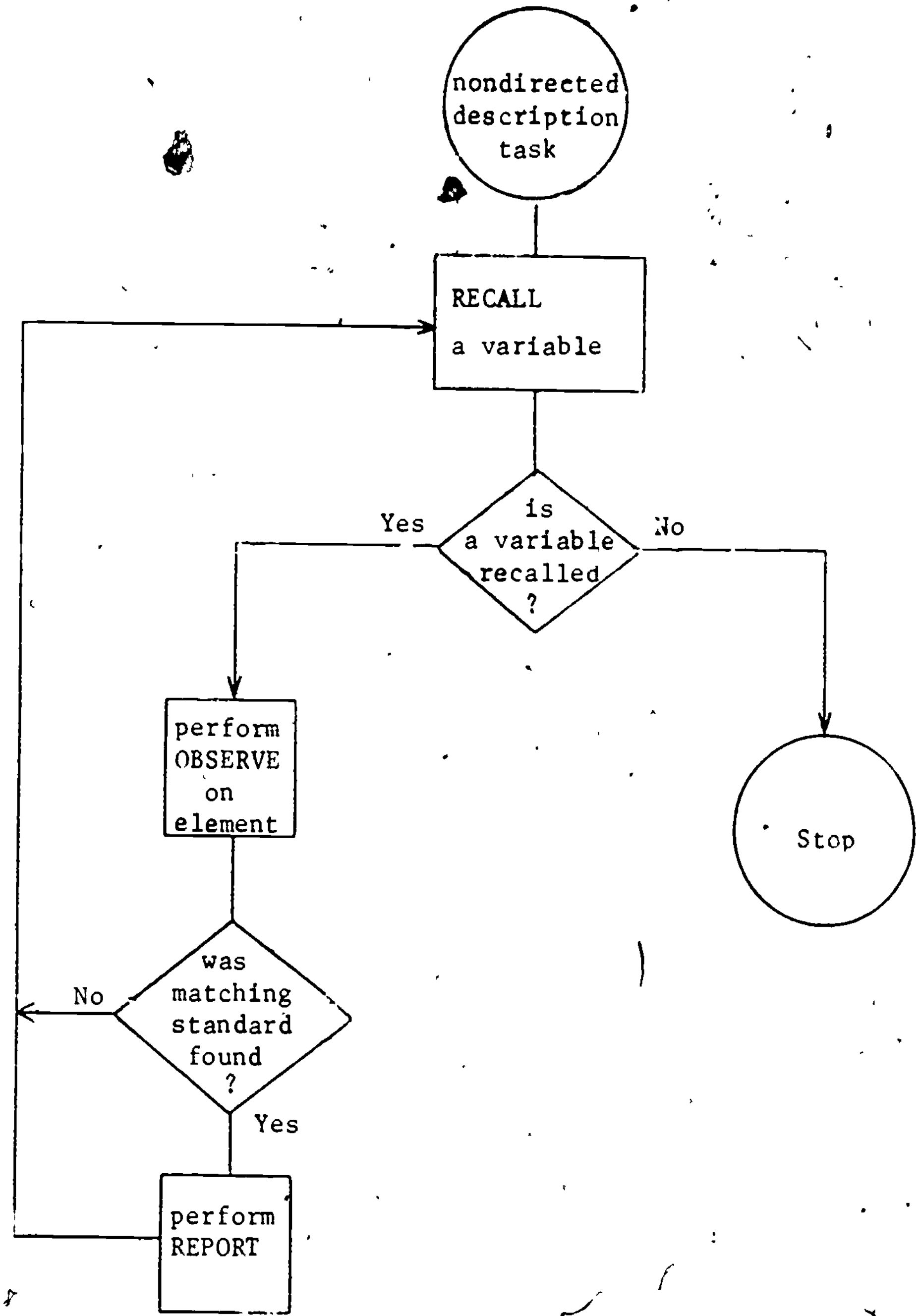

Figure 1. Processing routine for the nondirected description task.

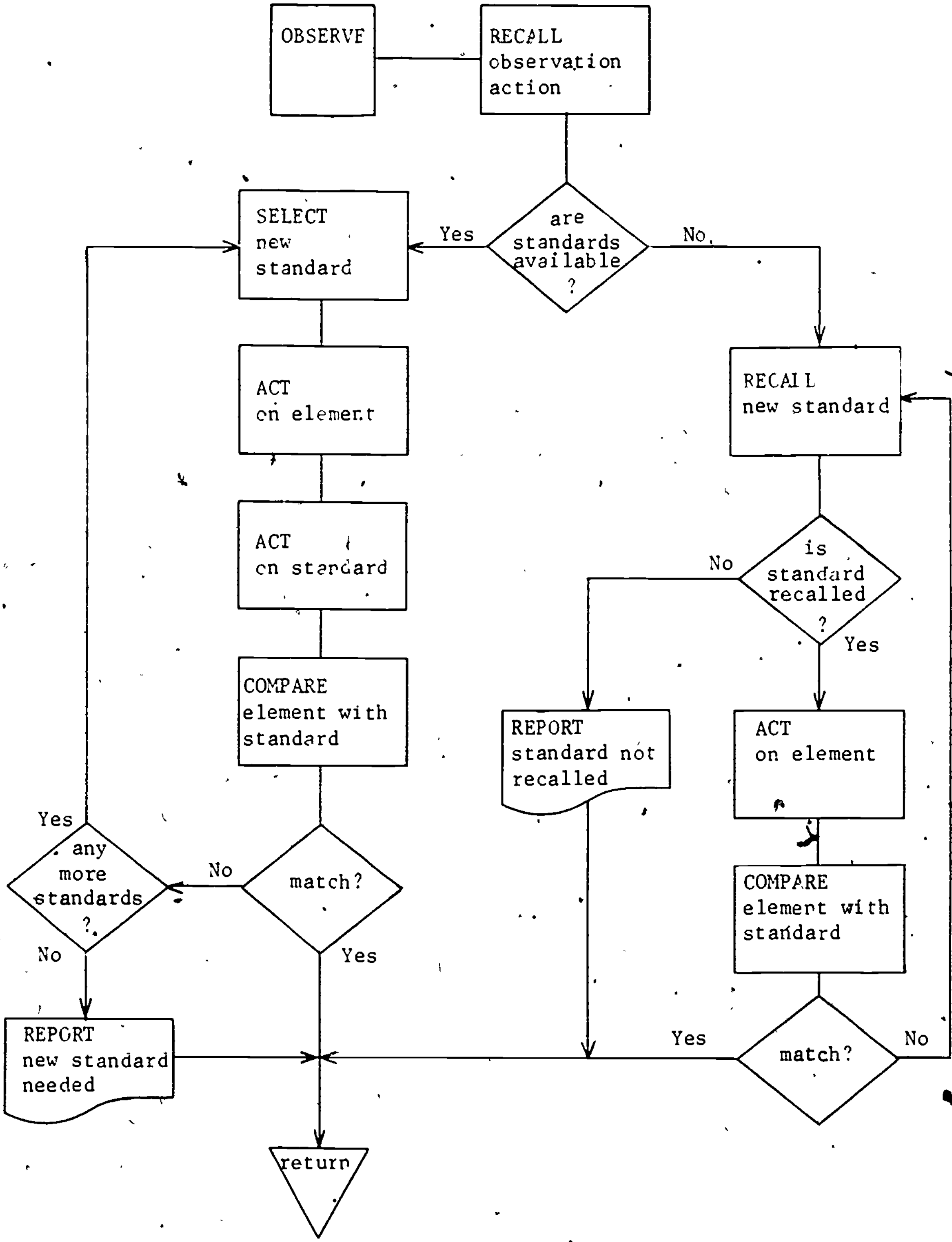

Figure 2. Subroutine for carrying out the observation procedure for a qualitative variable.

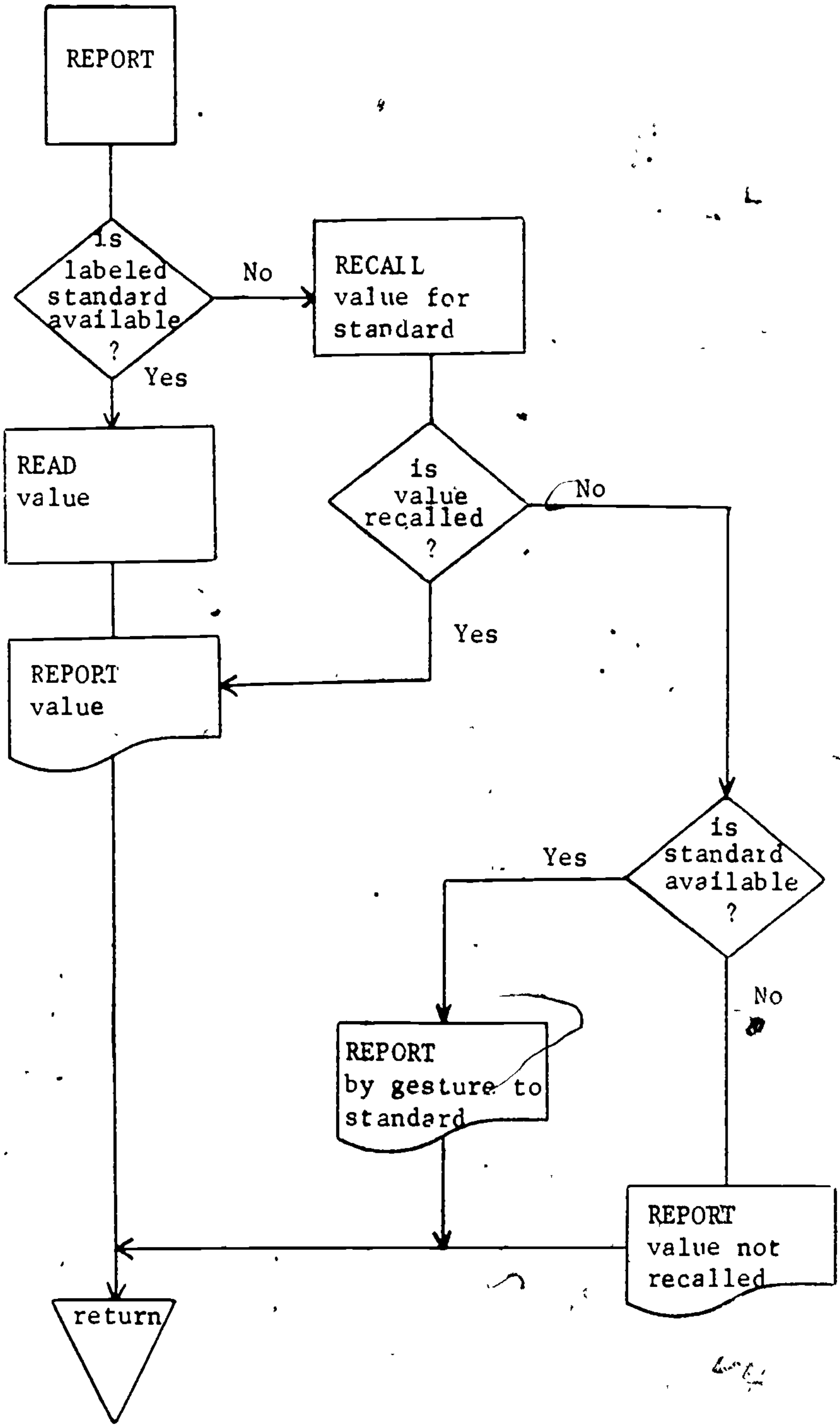

Figure 3. Subroutine for reporting results (values) for a qualitative variable.

name) of this object," is very similar to the nondirected description task with the difference that the variable is a given (rather than being selected by the child) and the element is described only on that variable. As indicated by a comparison of Figures 1 and 4, the processing steps involved in the two tasks are largely the same, with the main difference being that, in the directed description task, the child must decode rather than recall the variable name. The "observe" and "report" subroutines are used in both tasks. Decoding is viewed on the analytic level as a recognition of the kind of network involved and the role of the given component in that network (i.e., understanding that the task is associated with a variable-value network and that the given component is a variable name). Once the variable name is decoded, subroutines executed, and a value on the given variable reported, the directed description task is completed; there is no repeating of the routine, as in the nondirected task.

The element selection task, of the form "Pick out the object which is/has (value)," has as given components a set of elements and a value, and requires an observation/measurement procedure and the selection of an element described by the given value. The routine, diagrammed in Figure 5, involves an initial decoding of the value and identification of the procedure. The basic processes involved in the execution of the procedure are very similar to those required in the nondirected and directed description tasks (i.e., there is a search which terminates upon a matching of element to standard). The major difference is that instead of comparing one element with

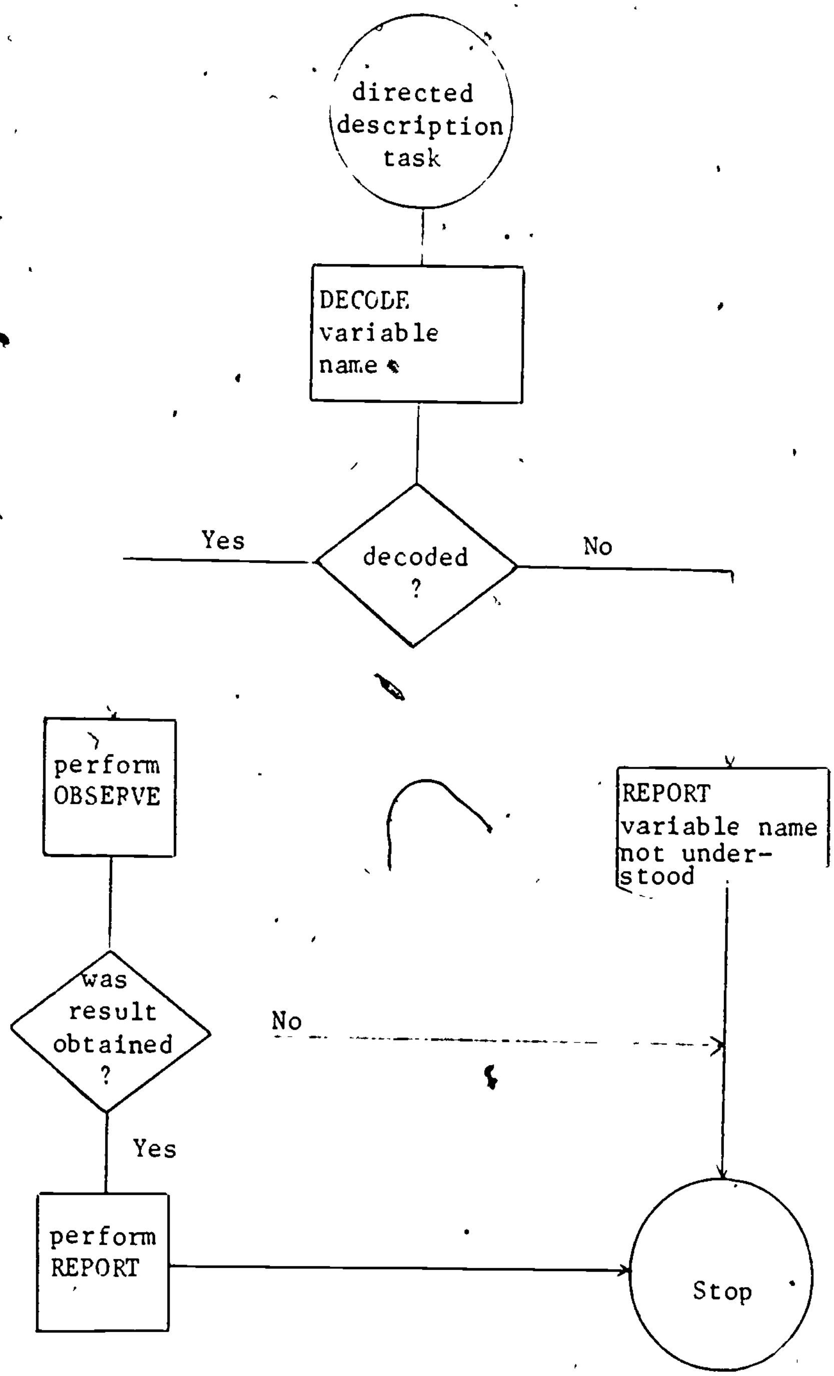

Figure 4. Directed description task processing routine.

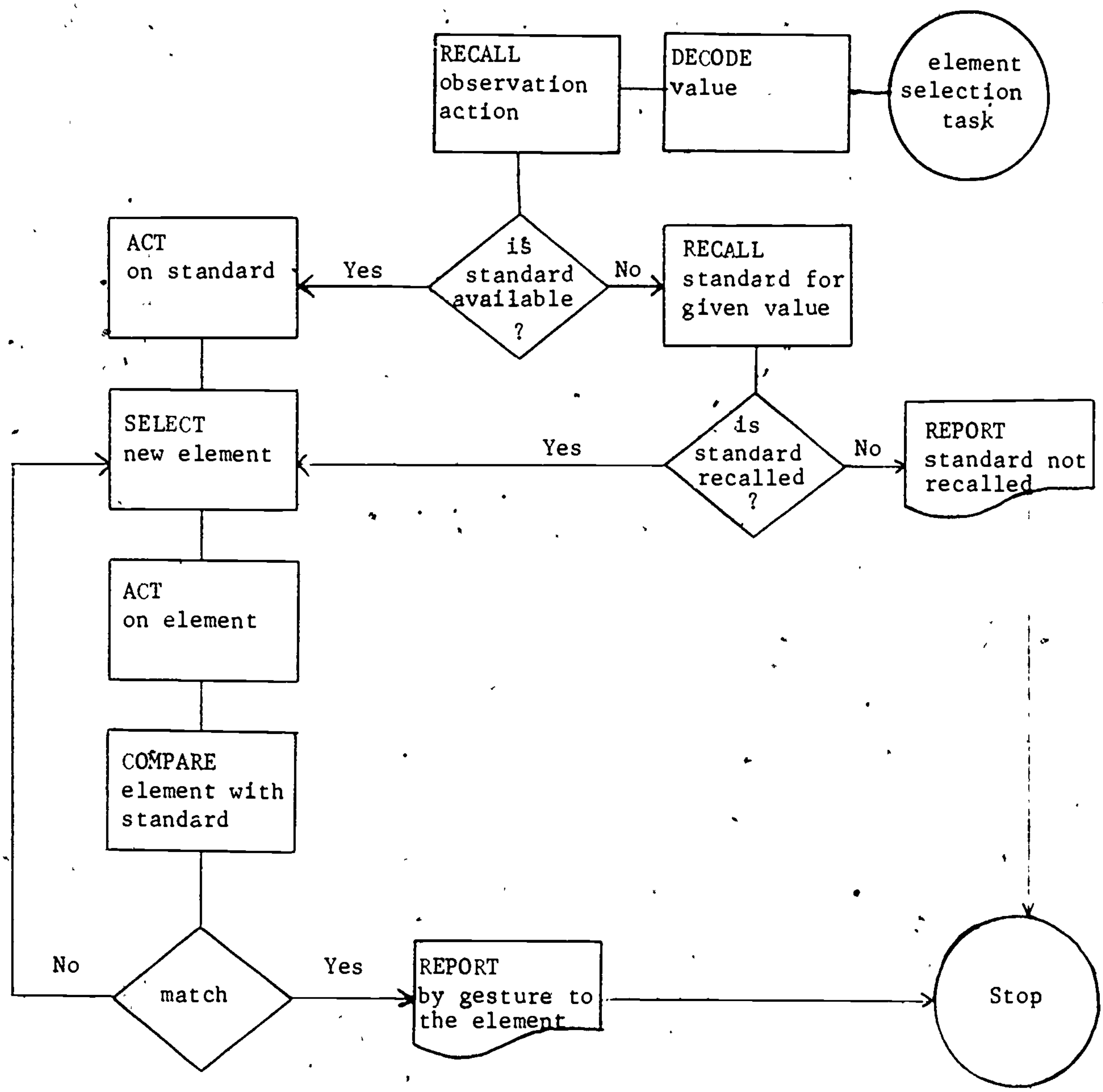

Figure 5. Element selection task processing routine.

more than one standard, the element selection task requires a comparison of the standard with more than one element. Also, since the value is given, the "report" may be simply a gesture to the matching element.

As evident in Figures 1-5, although routines for each description task differ in certain respects, there are many information processing requirements which are common to all three tasks. The processes of decoding and/or reporting variable names and values, recalling and executing an observation action, and comparing element features are invariant. Thus, at least within the limits of the defined area of content, there appears to be a set of basic description tasks which can be carried out by means of common skills.

VARIATIONS IN SYSTEMIC AND PARTICULAR CONTENT

Some distinctions among types of systemic and particular content have important implications for processes and strategies for a given task. The routines discussed above were developed principally in reference to systemic and particular content appropriate at the K-1 level, i.e., the description of simple elements, (e.g., discrete objects) in terms of common qualitative variables whose values are easily observed. Certain types of elements, variables and values will require strategies which deviate at some points with those diagrammed above. The distinction between qualitative and quantitative variables has already been mentioned; for quantitative variables the comparison of an element to standards involves an ordering as well as a matching operation. A subroutine for carrying out the observation procedure for a quantitative variable where standards are available is diagrammed in Figure 6. Note that another subroutine, "order" (Figure 7) is included in the observation procedure.

The form of the observation/measurement procedure can vary within the same variable as well as between different variables. The procedure described above involves a relatively simple perception of the element. Procedures which require several steps or which utilize measuring instruments necessitate additional and/or alternative operations in the routine.

Distinctions among general classes of elements (objects, constructs, events, symbols, etc.) also have implications for task strategies. For example, the observation/measurement procedure described above applies to concrete elements which can be perceptually encoded--things which can be seen, heard, touched, etc.--rather than to less tangible elements such as events, systems, or constructs whose description presumably involves more complex operations.

In general, while many content distinctions such as those mentioned above are associated with variations in the description routine, these variations appear to be specific and to affect only certain parts of routines or subroutines. For example, in the nondirected description task, quantitative variables or the use of measurement instruments or gauges in the observation/measurement procedure only affect certain segments of the subroutines diagrammed in Figures 2 and 3; the basic description framework as outlined in

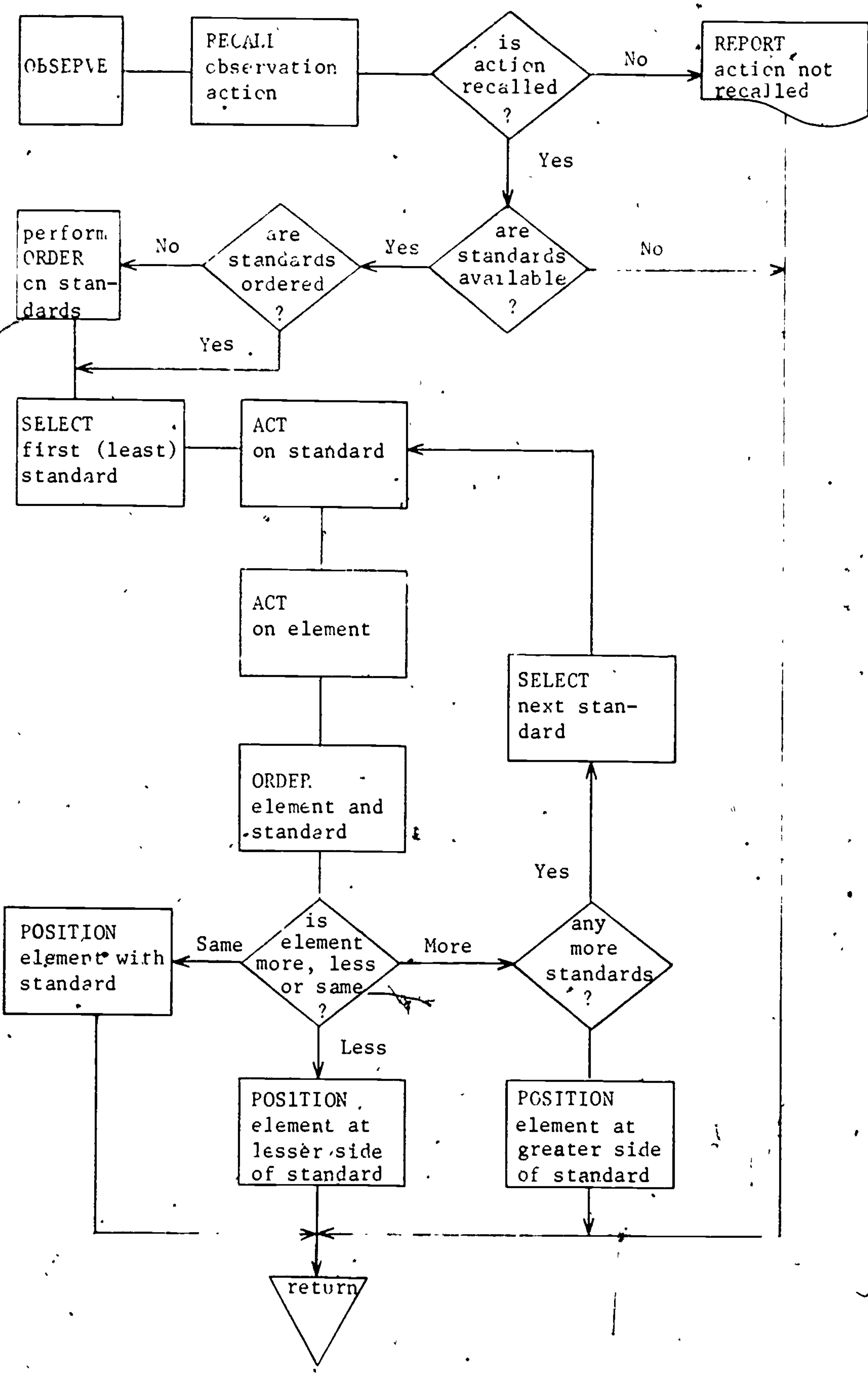

Figure 6. Subroutine for carrying out the observation procedure for a quantitative variable.

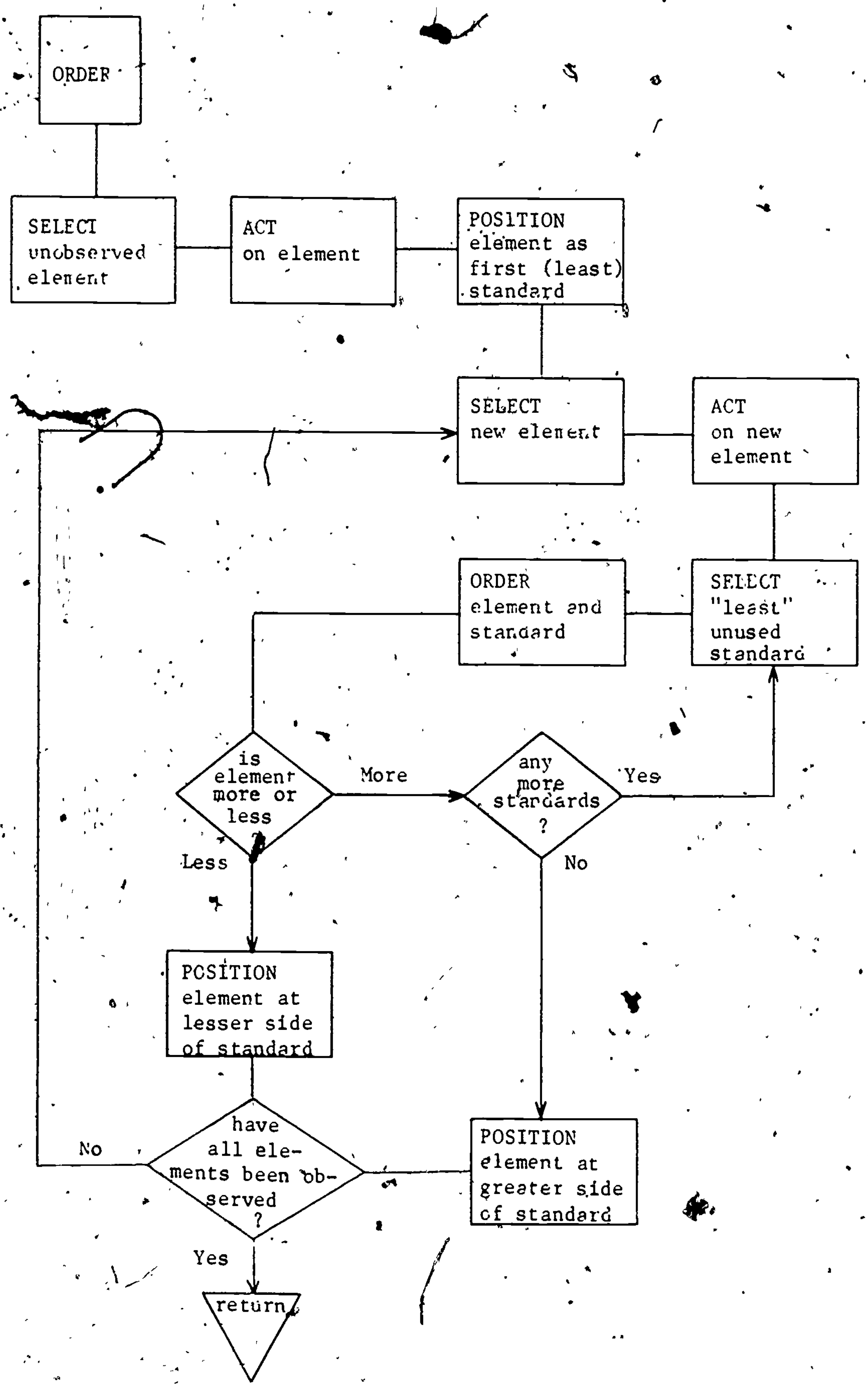

Figure 7. Subroutine for ordering elements (see Figure 6) for a quantitative variable.

Figure 1 remains the same. Although all possible types of content variation have not been analyzed, it appears that the basic structural sequence of the identification of variable and observation/measurement procedures, implementation of the procedure, and reporting of results does not change.

VARIATION WITH PRIOR LEARNING

In addition to changes in the processing steps required to accommodate differing content, the strategy may be modified according to the state of knowledge which has been acquired in relation to a specific systemic network.

The description strategies presented above were designed to permit successful performance of the task based only on a minimal introduction to the components of the variable-value system which is being utilized. After the child has had considerable experience in obtaining values from standards, and applying them to elements, it would be expected that fairly direct associations between the stimulus features, elements and values would be formed. Thus after considerable experience with a variable-value system, the child could be expected to considerably short-circuit the open description strategy, for example, by directly retrieving applicable values from memory and reporting them. After exhausting his supply of known values, he can then return to the basic strategy, taking care not to report values for variables already used.

Quite clearly, it would be possible to propose a somewhat different strategy in which it is assumed that feature-value associations are rote-learned first, and then used as a basis of description. However, such a strategy would not be nearly as flexible in accommodating modifications or expansions related to content, nor as effective in promoting transfer (i.e., learning-to-learn description tasks). A shortened strategy is inapplicable, for example in the case of a quantitative variable measured through the use of an instrument, regardless of how much experience the child has had with the variable.

FLEXIBILITY OF INFORMATION PROCESSING ANALYSIS

Information processing analysis is important as a tool for identifying a system of processing skills which is sufficient for successful task performance. For a given set of related tasks, the same basic system can be utilized, with variations made upon it when necessary. As noted above, the child need not develop whole new routines to accommodate systemic and particular content of different types and levels of complexity. Instead, existing routines can be made more complete with the addition of new subroutines.

Routines can also be modified so as to reduce the possibility of failure at any particular step in the routine. New subroutines can be added to facilitate recall or decoding of a piece of information or to provide a means of obtaining that information. The following are examples of possible routine modifications.

Various associations may mediate recall of information. In the process of recalling variables for the nondirected description task (see Figure 1), for example, the child mav be able to call up associations between sensory modalities and variables (i.e., by systematically asking himself "What properties can I see, hear, taste, etc.?") so that certain variables might be used that otherwise would not have been without this mediating step. This modification of the nondirected description task is diagrammed in Figure 8.

Associations between systemic level components might also be utilized as mediators to facilitate recall. Strengths of associations between systemic level components will vary. For example, for a given individual and a given variable, there may be a stronger association between the observation/measurement procedures and values of the variable than between the procedure and the variable name. For example, in the directed description task (see Figures 2-4), if the child cannot recall the observation/measurement procedure given the name, his recall may be facilitated by recalling values associated with the variable as diagrammed in Figure 9.

In many instances when a child cannot recall a necessary component or perform an operation, steps may be added to the routine to direct him to some resource where he can obtain information necessary to successfully complete that step in the routine (e.g., the child may go to a resource book, ask a question of his teacher, etc.). An addition to the directed description task which incorporates a simple example of resource seeking is illustrated in Figure 10.

Other types of aids which might be utilized to reduce task failure are of a syntactic nature. In the item form of a given task, clues to the network or the role of a given or required component may be available. For example, in the variable-value network, the syntax

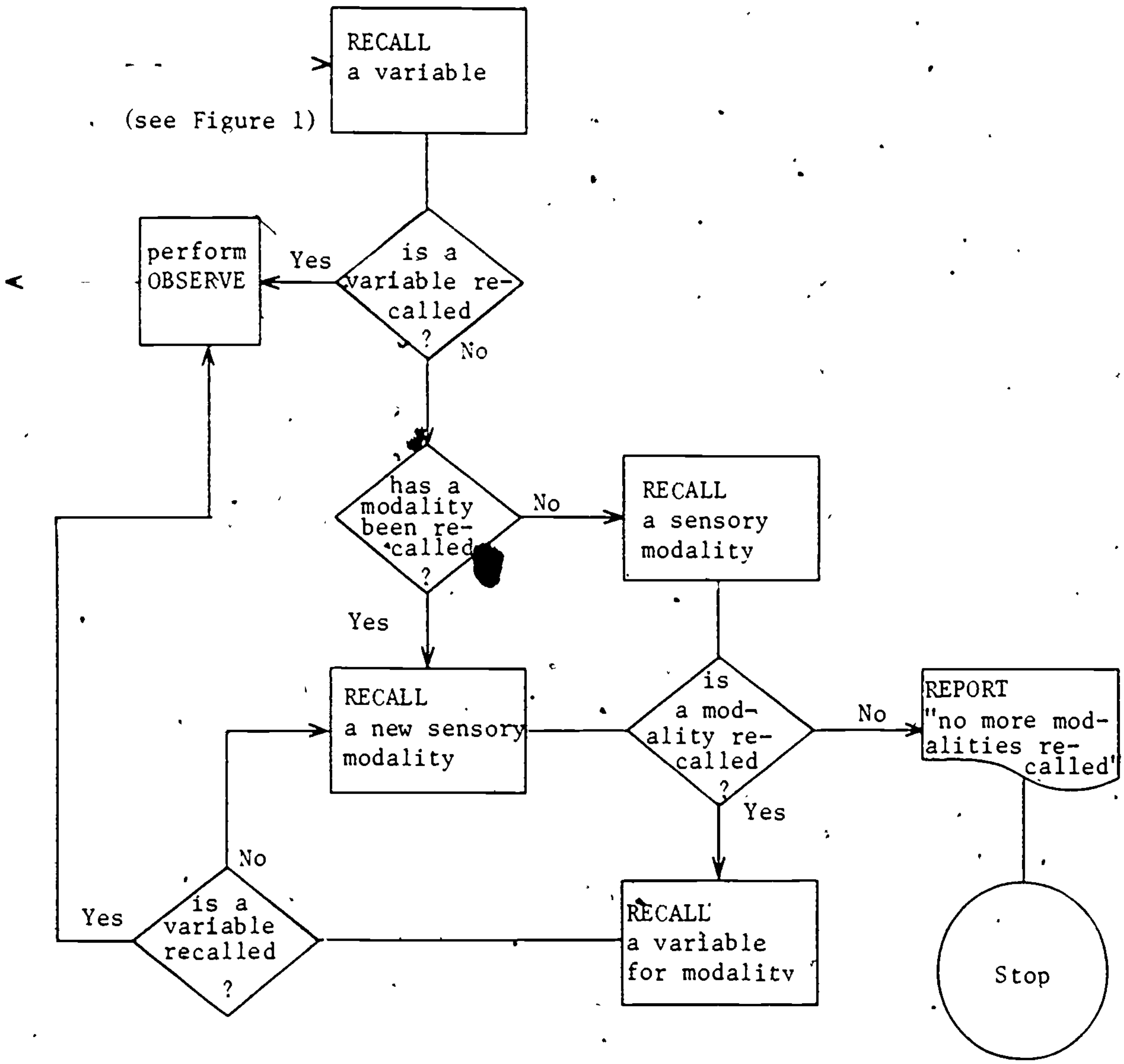

Figure 8. Modification of the nondirected description task routine (Figure 1) where variable recall is mediated by recall of sensory modalities.

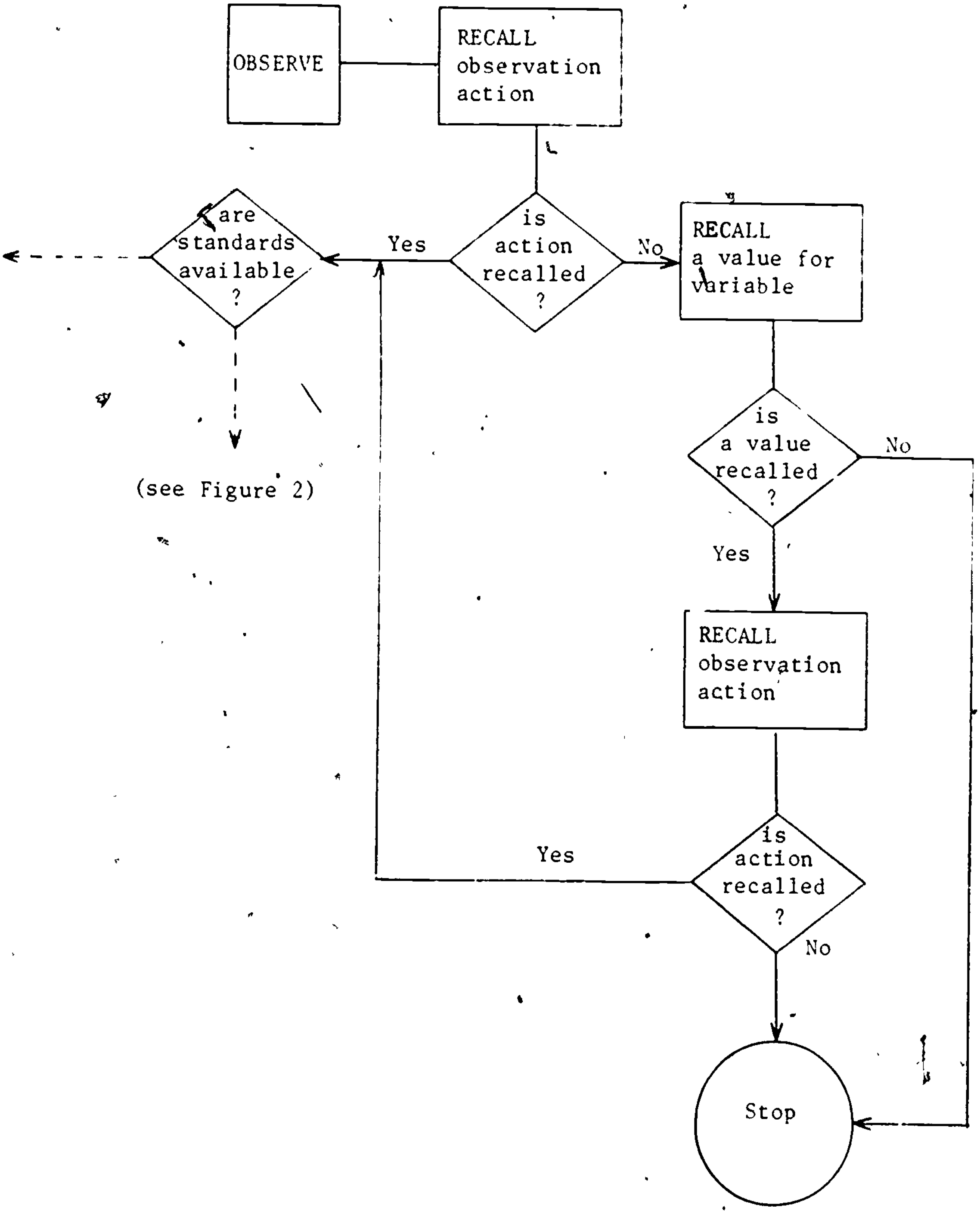

Figure 9. Modification of the OBSERVE subroutine (Figure 2) where recall of an observation action is mediated bv recall of values associated with a given variable.

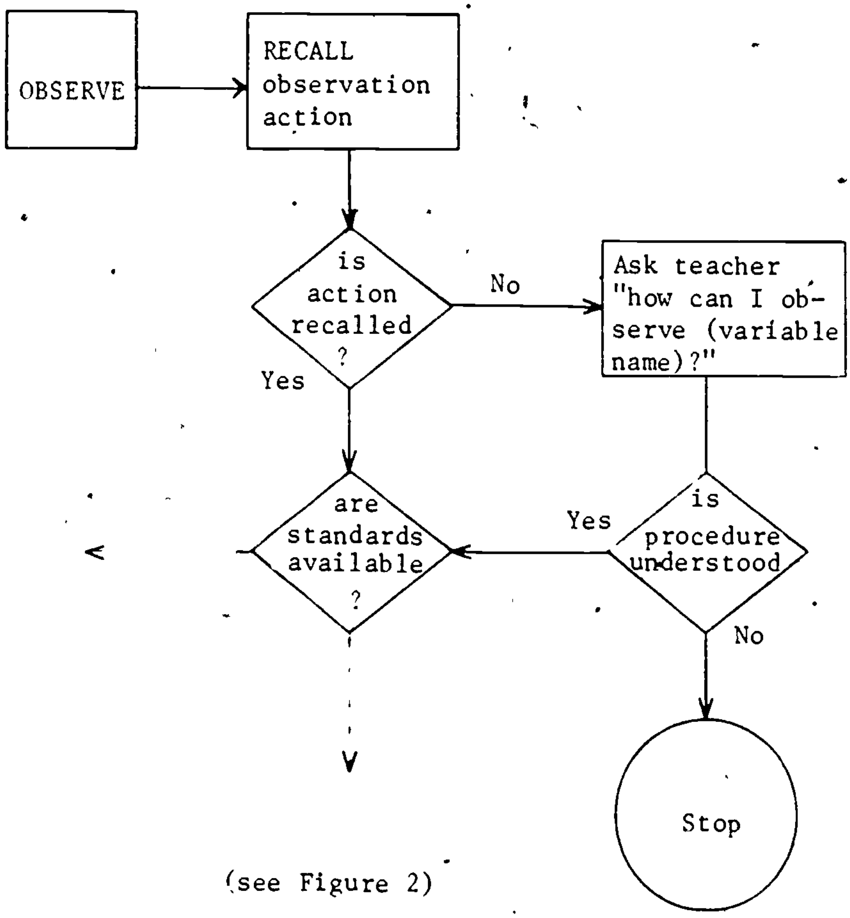

Figure 10. Modification of the OBSERVE subroutine (Figure 2) where an observation action is obtained through an example of resource seeking.

of the item shells, "What is the X of this object" and "Pick out the object which is Y" helps to identify X as a variable name and Y as a value. Thus subroutines which discriminate syntactic structure of item shells might be useful in identifying the task and selecting an appropriate strategy. The analysis of syntax involved in task instructions or verbal responses is important in specifying some aspects of language relevant to instruction in particular disciplines.

PSYCHOLOGICAL INTERPRETATION OF PROCESSING ROUTINES

In the preliminary routines described above, strategies consisting of sequences of processing steps sufficient for successful task performance have been identified. These were not, however, defined precisely in terms of the psychological mechanisms involved. In the second phase of skills analysis, the processing steps are interpreted as specific psychological mechanisms. Thus, the preliminary routines specify the problems which need to be solved by reference to the relevant psychological literature. For example, many of the preliminary routines involve the recalling of certain verbal labels and procedures.

The psychological interpretation of recall steps requires the adoption of hypotheses concerning the nature of the storage of such items in memory and the processes by which they are retrieved. These hypotheses are reflected in the selection and definitions of primary processes in terms of which the final processing routines are defined.

The level of specificity and detail required in the definition of primary processes is itself an hypothesis, at least initially. The adequacy of such hypotheses is judged primarily by the utility of the resulting processing routines, (i.e., by the success of instruction based on them in achieving task mastery and predicted transfer effects). The initial hypothesis is that definition of primary processes in terms of input/output relations is sufficient. The resultant demands to be made on a model of long-term memory in defining primary processes for recall therefore include specification of the nature of the information stored, the kind of information which can ~~be used~~ to gain access to stored information and the major processing steps distinguished.

Frijda (1972) describes a model of long-term memory, some version of which is utilized in nearly all information processing theories and simulations. According to this view, information store is an associative network of items or nodes, each leading to any number of other nodes--the associations of the first node. The stored items or nodes are generally considered to be concepts or ideas themselves rather than names used to refer to them or images exemplifying them. Although this is a somewhat vague position, the important point seems to be that what is stored is not words or images but rather information from which words, images and actions are reconstructed, as proposed by Neisser (1967). Thus, once activated or accessed, a node makes immediately available a number of operational options. Nodes are accessible by way of other nodes to which they are linked, or by way of items or stimuli that in some sense resemble them (i.e., that resemble some level of reconstruction) or through the decoding of labels that refer to them.

Figure 11 illustrates an associative network which might be drawn upon for performance of tasks such as the directed description task using the processing routine presented in Figure 4. The nodes represent the relevant systemic concepts. In carrying out the directed description task for example, access is acquired to the network through processing the variable name. This involves the decode primary process. Decode takes the variable name as input and, since it activates the "variable X" node in the network, can be said to output the variable X concept. The "output" of a decoding step might perhaps be better termed a result. In effect, the decode process opens the way to many possibilities, but it remains for the next step(s) to take advantage of one or more of them. The possibility that the individual may be set to perform another step which then follows automatically from the decoding need not concern us here. The point is that access to the storage network must be gained as a result of the given variable name. This is the defined function of the decode process.

Although many alternative processing steps are made possible by the decode process, some directing mechanism insures that access to the observation action node is gained as the next step. This involves the recall primary process. The nature of the directing mechanism has not been further elaborated. At present it seems sufficient to state that this mechanism is capable of directing the recall process to

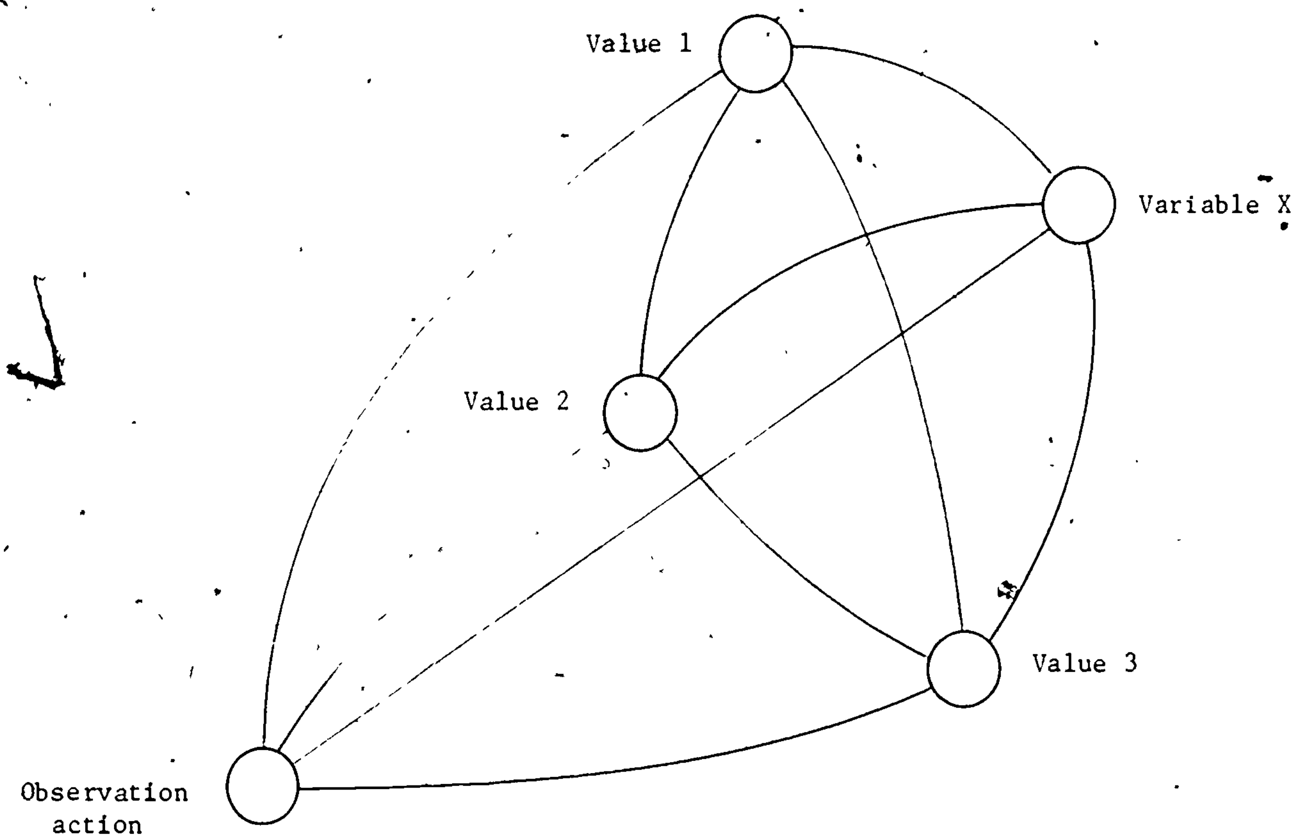

Figure 11. Stored association network for a variable-value conceptual system.

a connected node which is related to the original node in a specific way. Thus, the input of the recall process can be characterized as one concept and its output as another concept. It should be noted that the recall process, just as is the case with the decode process, does not output any images, words or actions.

Once the observation action node has been activated by recall, an action program can be reconstructed which guides the carrying out of an observation action. At present no distinction seems needed between the reconstruction and execution of the action program. Thus, the act primary process implies both. Alternatively, a verbal description of the action could be reconstructed first to mediate the reconstruction and execution of the action program. Both steps represent operational alternatives made available by the activation of the observation action node.

Similar interpretations can be given for each part of the preliminary processing routines based on the relevant psychological literature. The above examples suffice to illustrate the process. The immediate result is a final processing routine for each task and a definition of each primary process involved in them. Subsequent analyses can utilize the primary processes previously defined, thus, the psychological interpretation phase will require less hypothesizing concerning the nature of the processes themselves as more final processing routines are prepared.

An important benefit from the psychological interpretation of the processing steps is the information made available about the influence of independent variables upon them. Existing knowledge of the effects of such variables can be used in the design of instructional strategies and in studies designed to test hypotheses that particular mechanisms are being employed. Without detailed skills analysis it is impossible to take advantage of such knowledge since there is only the vaguest notion of the processing involved and therefore what literature is relevant.

CONCLUSION

Preliminary processing routines such as those presented in the first sections of the paper specify a strategy for carrying out a task and the general nature of the processing steps required. Thus, applicability to a domain of content can be determined before more detailed analysis is carried out. When their applicability has been judged adequate, further analysis utilizing current knowledge of the relevant psychological processes can be carried out. This stage of analysis recasts the routines in terms of primary processes such as those briefly described in the previous section. These final routines provide the basis for predicting transfer relations among learning outcomes and designing instructional strategies drawing on the relevant psychological literature.

It should be recalled that the information processing strategies which have been presented are not intended as a description of how students actually do perform such tasks. The question of whether these strategies are valid or invalid as descriptions is not relevant. They are conceived as a description of one feasible and reasonable efficient way of performing such tasks, and as being trainable by some instructional procedures. The relevant criteria for evaluation ask: 1) Can instructional procedures be devised which result in acquisition of the intended strategies in a reasonable segment of instructional time? 2) Is the strategy effective, when carried out, in producing valuable behavior? and 3) Are the processing routines useful in predicting transfer relations among related learning events? Whether or not the intended strategy is a valid description of behavior is a relevant question only in relation to children who have received instruction designed to produce the strategy.

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II. Applications to Science

Working Paper 3

ANALYTIC CONCEPTS AND THE RELATION BETWEEN CONTENT AND PROCESS IN SCIENCE CURRICULA

Edward L. Smith

What relative emphasis should be placed on the learning of content (concepts, definitions, principles, etc.) as opposed to processes (strategies, procedures, etc.) in elementary science education? The major projects developing elementary science curriculum materials in the last decade illustrate the spectrum of opinion on this question.

Several projects, such as the *Conceptually Oriented Program in Elementary Science* (COPES, 1967) and the *Cornell Elementary Science Program*, (CESP, 1969) placed major emphasis on content. The content oriented programs were influenced by Bruner's argument that any knowledge can be taught to anyone at some intellectually valid level (Bruner, 1966), by Ausubel's argument for the importance of meaningful reception learning (Ausubel, 1963, 1968), and by efforts of the National Science Teachers Association to develop a consensus on the major conceptual schemes of science (NSTA, 1964, 1966). These programs reflect the view that mastery of basic concepts and principles is the basic requirement for further learning and problem solving.

Taking quite another position was *Science: A Process Approach*, a program sponsored by the American Association for the Advancement of Science (AAAS, 1967). Content was viewed as temporary or unstable, changing with the rapid development of new knowledge, and as not being broadly generalizable. A more enduring and general foundation was sought in basic processes of science. The program was heavily influenced by theoretical views of Gagné on skills and task analysis.

Although considerable emphasis was placed on tryout and revision (formative evaluation) of all of these programs, most assessments have been concerned with the achievement of rather specific objectives. To date there is insufficient data concerning the relative impact of the programs (summative evaluation) to provide an empirical answer to the question of the optimal emphasis to place on content and process in the long-range development of general science skills. Despite enthusiastic argumentation by proponents of each side, there is no evidence to suggest that either approach should be discarded entirely. Every scientific field necessarily involves elements of both content and process. If science education is to reflect anything of the nature of science, some contents, some processes, and some relations between them must be included.

Such a balanced approach should not be simply a potpourri of objectives from each side. Rather, an analytic base having its own integrity should be employed as a means of coordinating content and process. Thus, the main question debated by science educators should concern the <u>relation</u> between content and process, not merely the degree of emphasis to be given to each.

The ideas presented in the following paragraphs provide a preliminary answer to this question and indicate how an appropriate analytic base for a science program can be designed. The approach described below has been found similar in several respects to that implicitly employed by the Science Curriculum Improvement Study (SCIS, 1966, 1968a, 1968b, 1968c). By making the analytic base explicit, precision can be increased, and inconsistencies and other problems can be discovered and solved at the design level (see Smith & McClain, 1972; Smith, 1971).

Three levels of program content are distinguished: the analytic, the systemic, and the particular. The most general and stable aspects of science are the analytic concepts such as variable, operation, system, relation, hypothesis, etc. Analytic concepts are abstractions from the systems of content of particular disciplines. They reflect the structure or form of that (systemic) content, rather than its substance. Mastery of analytic concepts provides a basis for organizing investigation into new areas, whether first hand or through secondary sources. Sets of analytic concepts organized into networks can provide the framework for curriculum design. One such network, built around the concept of a variable, has already been developed (Smith & Van Horn, 1971) and applied to the analysis of outcomes of an extant primary science unit (McClain & Smith, 1971; Smith, 1971).

Somewhat less general and stable are the systemic concepts, those specialized concepts basic to the conceptual systems of specific disciplines. Force, energy, atom, ecosystem, cost, profit, role, response, need, etc., are important systemic concepts in their respective disciplines. A variety of such concepts is an essential ingredient of a curriculum designed to develop analytic concepts since the systemic concepts exemplify the analytic concepts. Concepts at this level are also required as a basis for assimilation of specific phenomena or information about them. Without an appropriate framework of such concepts the individual must construct his own. In general, naive inductions are unlikely to be an effective basis for discovery of new relations, or for accurate comprehension of new scientific information. Although less general than the analytic concepts, systemic concepts do have considerable generality in the diversity of phenomena to which they apply.

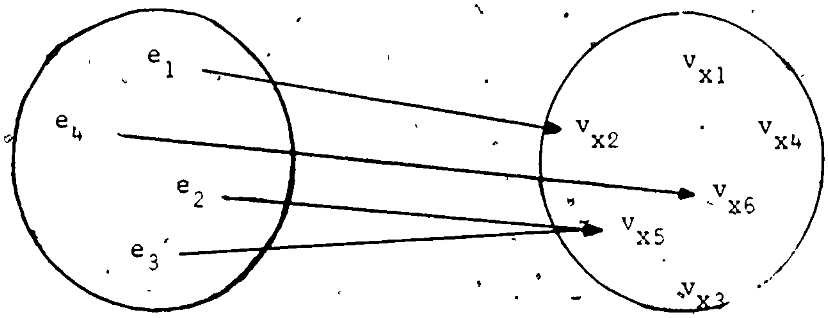
The third level of content is represented by the <u>particular</u> phenomena with which the student deals in the curriculum. The student may encounter the concept of weight in the context of the weights of himself and others in his class, for example. The content at this level can be viewed as a sample of the phenomena with which the student might come into contact. This domain is very large and heterogeneous, varying across individuals as well as over time. Thus, this level of content is the least general and the least stable.

The analytic, systemic, and particular levels of content represent three distinct levels of analysis and decision making. Analysis and subsequent selection of analytic content does not determine the systemic or particular content although it does establish criteria. Analysis of the conceptual systems of various disciplines must, then be carried out. Content selections at this level must exemplify the analytic concepts already selected. Finally, particular content which exemplifies the systemic content can be selected. Additional criteria can and should be adopted for selecting among systemic and particular content alternatives which meet the compatibility criterion.

The discussion above reflects what is typically referred to as content. However, the process aspect is not an independent component. Concepts are not static constituents which the individual merely possesses; they are functioning structures with functional consequences in behavior. In this sense processes are implied by the phrase, "mastery of the concept." Particular functional capabilities of the student with respect to a given concept cannot be assumed or left to chance, however. They must be clearly specified, given appropriate instructional attention, and carefully assessed.

At the analytic level, processes are represented by <u>analytic operations</u> defined in terms of the analytic concepts. It is quite probable that these operations can be adequately represented symbolically in a formal system. Initial attempts employing set theory have been moderately successful (Smith & Van Horn, 1971; McClain & Smith, 1971; Smith, 1971). For example, the <u>description</u> operation is defined as a many-to-one mapping of elements (the things to be described) into a set of values for the variable on which the description is made (see Figure 1).

Detailed specifications of tasks to be performed can be prepared at the analytic level by specifying the analytic operations the student must perform, and indicating the analytic concepts for which examples are identified in the task situation and those for which the student must provide appropriate examples for himself. For example, one description task provides the student with the elements and a variable name. The student must contribute the values and the observation/measurement procedure in carrying out the description operation.



Elements Values for Variable x

Figure 1. A mapping formulation of the description operation.

At the systemic level, processes are represented by algorithms or procedures exemplifying analytic operations. At this level the description task above might involve the measurement of weight using a spring scales calibrated in pounds, for example. Although limits on the sets of possible elements may be specified at the systemic level, the final selection of elements (and weight values) represent decisions at the particular level. Thus, the specification of the children in the classroom as elements to be weighed would represent a decision at the particular level.

As formulated above, development of the processes of science is not an alternative to the learning of science content, but rather one aspect of what is implied by mastery of such content. If properly organized, each learning event can serve to develop knowledge of specific phenomena, important systemic concepts, and generalizable analytic concepts. Without such organization, processes become isolated procedures with little meaning, power, or utility. Certainly skill in measuring weight has no more generality or stability than the concept of weight. Of course, these effects are not automatic results of any arbitrary science activity. Detailed analysis and careful selection are required. Further, instructional techniques which make the relations between the levels functional for the student must be identified. Undoubtedly, verbal mediation will play an important role. However, the optimal time for introducing analytic and systemic concept labels, optimal sequencing of examples, and other instructional problems must be investigated.

IMPLICATIONS FOR THE DESIGN OF A SCIENCE PROGRAM

The above remarks have several implications for the design of a science program.

1) A set of analytic concepts should be selected before final selection of content at the systemic level. Systemic content can be used as raw material for analysis to identify or assess the generality of analytic concepts. However, if the systemic content is to serve as a vehicle for the development of analytic concepts, the final selections and organization at the systemic level must be based on decisions made at the analytic level.

2) General terms such as deduction, observation, prediction, etc., which suggest operations must be defined precisely in terms of analytic concepts before they can become useful as a basis for decisions at the systemic and particular levels. Precise definitions also make prerequisite relations

among such operations more apparent, thus facilitating their selection and sequencing.

3) Criteria for the selection of analytic content must be established. These might include:

   a. Readiness of children to master as indicated by empirical and theoretical literature.

   b. Generality of application to systemic and particular content of interest and/or significance to the students.

   c. Time and effort required to develop a suitable level of mastery.

   d. Relevance to other, higher level analytic content.

ANALYTIC CONCEPTS FOR THE PRIMARY SCIENCE CURRICULUM

A preliminary set of analytic concepts for use in the primary science curriculum is described below. The concepts were identified as broadly applicable in analyses of extant instructional programs (Smith & McClain, 1972). Revisions may be made as tasks are defined and instructional strategies for their development are designed.

Most analytic concepts are defined in terms of their relation to other analytic concepts and derive their utility from those relations. It seems appropriate, therefore, to describe <u>networks</u> of interrelated analytic concepts. Although almost all such concepts may be related in the context of at least some systemic content, there do seem to be clusters which often function independently. The networks described below reflect the lowest level at which the concepts seem to function independently. Interactions among the networks will be defined at a later time.

ELEMENT-VALUE-VARIABLE NETWORK OF ANALYTIC CONCEPTS

A very basic network of concepts involves the entities whose nature is the subject of study and the features of those entities which are used to describe, compare, order, and classify those entities. These analytic concepts have been described in considerable detail elsewhere along with analytic operations and tasks defined in terms of them (Smith & Van Horn, 1971; Smith, 1971). Brief definitions of these concepts are presented below:

Elements--The entities (objects, events, systems, constructs, etc.) which are being studied.

Variable Name--Name of an aspect of elements which may vary either from element to element or for one element across time.

Values--Terms representing particular element characterizations distinguished with respect to a given variable.

Observation/Measurement Procedure--Rule or algorithm which, when applied to an element, results in the specification of the value of the corresponding variable which applies to the element.

Description--A set of values consisting of one value for each of a set of variables.

Comparative--Term representing the relation between the values of a single variable (or descriptions on a set of variables) which characterize two or more elements (or an element at different times).

Correlational Rule--Rule or algorithm which, when applied to a value of one variable, results in the specification of a value of a different variable.

THE CLASS-MEMBER NETWORK OF ANALYTIC CONCEPTS

A broadly applicable and widely studied network of concepts is based on the notion of class membership. This network also includes the concept of element. Other concepts involved are defined as follows:

Class--A particular set of elements.

Class Member--An element which is in a particular class.

Class Definition[1]--A decision rule which when applied to a description of an element, specifies whether or not the element is a member of the corresponding class.

Class Name[2]--Label applicable to any element which is a member of a given class; also used to refer to the class as a whole.

WHOLE-PART NETWORK OF ANALYTIC CONCEPTS

This analytic network is based on a special relation between elements. Each element in the relation is viewed simultaneously at two levels. Each is viewed as an element. At the same time, the "whole" is viewed as being divisable and the part as a result of a division. In other contexts, each may be viewed simply as elements.

Part--An element which is an integral portion of another element.

Complex Element (whole)--An element which is regarded as having two or more parts.

Activity--A characteristic functioning or behavior of a complex element (activity implies complexity, i.e., parts).

Function--The action or contribution a part makes toward an activity of a complex element of which it is a part.

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[1]Definitions of classes are a form of correlational rule since they relate values of one variable (the alternative classes) to those of one or more other variables (those on which the descriptions are based). They are true by definition, however, since there is no independent means of assigning values.

[2]Class names serve as values in statements asserting class membership for elements or relating class membership to other characteristics.

PROCESS-STAGE-EVENT ANALYTIC NETWORK

None of the analytic concepts described above deal explicitly with the temporal aspect of phenomena although the values and comparatives can be employed in describing changes. This aspect seems basic and important enough to warrant specilized treatment. The following concepts deal explicitly with the temporal aspect of phenomena while relating it to the structural or spatial aspect.

Change--A change is the applicability of two different values of a variable to an element at two different points in time.

Event--The occurrence of a change or set of coincident changes in an element.

Process--A set of temporally ordered changes in an element on a given set of variables.

Stage[3]--Part of a process consisting of (a) a sequential subset of events, or (b) a period of time bounded by specific events.

APPLICATION OF ANALYTIC CONCEPTS IN CURRICULUM DESIGN

The role of analytic concepts in the design of a science program is illustrated by the application of the analytic concepts defined above to a list of proposed content for a kindergarten science program (see Appendix A). The list was specified and organized at the systemic level. The reorganization resulting from the application of the analytic concepts (Appendix B) provided the basis for the following discussion and recommendations. These comments consider

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[3]Sometimes the form an element takes during a stage is referred to as a stage. This is considered to be an implicit statement of "the form x takes during stage y." The stage may be identified by the form taken during that stage, e.g., larva stage.

only the relation between the analytic and systemic concepts and do not reflect evaluation of the systemic concepts themselves.

In considering such recommendations, it is important to keep in mind the assumption, developed above, that the primary contribution of systemic concepts is the development of the analytic concepts which they exemplify. It is the analytic concepts which provide a mediating device for the facilitation of learning of new systemic content (parallel transfer) and the development of generalizable inquiry strategies. It should be recalled that this does not eliminate the necessity for mastery of systemic content, however. To the contrary, mastery of systemic concepts is essential, for it is these which exemplify the analytic concepts.

1. When viewed from the analytic level, several gaps are revealed in the proposed lists of systemic content. For example, several lists of parts on page 24 do not have any functions specified. Only a few of the class concepts on pages 26 and 27 have any values specified which serve as definitions. Gaps at the systemic level will result in gaps at the analytic level. They also reduce the power and usefulness of the systemic content in the assimilation of particular content. <u>It is recommended that systemic content be added to fill in these gaps.</u>

2. In some cases, sets of systemic concepts did not fit any analytic network very well. The phenomenon of burning, for example (see page 31), could be treated with whole-part

concepts or with process-stage-event concepts. However, the proposed list of systemic concepts does not seem to completely fit either. Such mismatches might be due to inadequacies in the analytic networks or to inconsistencies in the systemic content. Whatever the reason, difficulties in learning could result at both the analytic and systemic levels. Systemic content, particularly at the primary level, should exemplify specific analytic networks. <u>It is recommended that where unresolvable mismatches occur, the systemic content be postponed until a later time.</u>

3. The proposed list is probably too extensive to allow adequate development of all the systemic concepts in a single kindergarten program, particularly if the first recommendation above is heeded. The number of systemic concepts can be reduced by using fewer examples of each analytic concept or by adopting fewer analytic concepts. Development of concepts in primary children requires experience with a number of examples.[4] While the optimal number of examples is not known, it would seem wise not to cut the margin too thin on the first pass. Thus, in order to allow time for a sufficient number and variety of particular examples of each systemic concept, <u>it is</u>

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[4]Examples are not necessarily real world objects and events. Linguistic usage of concept labels can also function as examples. Although some real world examples are undoubtedly necessary at the primary level, appropriately structured linguistic examples can probably make a considerable contribution.

recommended that the number of systemic concepts be reduced by adopting fewer analytic concepts for emphasis in the kindergarten program.

4. Although analytic concepts are the most broadly generalizable, many systemic concepts do have considerable generality in the variety of particular content to which they are applicable. Systemic concepts applicable in several of the particular subject matter areas covered in the list are sometimes employed only in one. For example, the variables "time of day" and "number" (page 29) could easily be employed in the living things areas as well as the universe area. To increase the probability of adequate mastery, it is recommended that the systemic concepts be explicitly employed in more than one subject matter area whenever possible.

5. The content list does not include any correlational rules (e.g., animals that eat grass have flat front teeth). It is assumed, however, that some concepts of this type will be included in the program. Specification of the correlational rules in which a variable is used is an important step in selecting variables to include. Thus, it is recommended that correlational rule concepts be specified before selection of variable concepts is made. For example, potentially useful correlational rules might relate kind of habitat and kind of body covering, kind of habitat and kind of part used for moving, kind of motion and kind of part used for moving, and temporal sequence and stage of development.

CONCLUSION

This paper began with the formulation of the question, "What is the relation between content and process in the science curriculum?" This relation was defined in terms of analytic concepts. The development of generalizable strategies for processing information requires some characterization of the form of the information to be processed. Analytic networks such as those described above provide a basis for consistently organizing systemic content in standard forms. These forms can be gradually abstracted by the students under the guidance of verbal labels and definitions introduced at appropriate levels. This represents mastery of the analytic concepts themselves. The analytic concepts are then available as a mediating device for obtaining and/or organizing new information of the same forms.

Rather than as an achievement apart from the mastery of concepts, facility with processes of science is viewed as the operational aspect of the mastery. The processes emerge as operations defined in terms of analytic concepts. As these are repeatedly exemplified at the systemic level, they are brought increasingly under the student's control. Mastery at the analytic level implies the ability to organize new information in an appropriate form employing procedures appropriate to that form, i.e., exemplifying the corresponding analytic operations. The operational aspect of analytic concepts will be treated in detail in subsequent papers.

If a science program is to have an impact beyond the mastery of specific systemic content, the selection and organization of that content must be based on decisions at the analytic level. However, these decisions are not a sufficient basis for selecting systemic content. Additional criteria such as those proposed by Babikian (listed in Appendix A) are needed. Particularly important from a design point of view are criteria concerning the prerequisite relations with sets of higher level systemic content.

It should be added that no explicit criteria for selecting analytic concepts have as yet been developed. The selections of analytic concepts for the present paper were based on their occurrence in a highly regarded extant program and a subjective evaluation of their reasonableness and generality. The suggestions on page 88 might serve as a starting point for developing such criteria.

APPENDIX A

SUBJECT MATTER CONCEPTS
KINDERGARTEN SCIENCE PROGRAM

Elijah Babikian

November 1971

I. Criterion questions for the selection of K science concepts.

1. Are the concepts consonant with the intellectual maturity of the learners?
2. Can they be taught meaningfully by first-hand experiences?
3. Can they be taught by simple, low-cost, and safe materials?
4. Can they be taught by experiments which guide the learner to discover the concept himself?
5. Do they arouse and/or sustain students' interest?
6. Do they help the children to acquire specified inquiry skills?
7. Are they related to the immediate environment of children?
8. Do they represent all of the five subject matter domains: living things, non-living things, energy, earth, universe?
9. Do they represent all of the five levels of concept abstractions: properties of matter, diversities in nature, interaction in nature, change in nature, and development in nature?
10. Are they expandable, horizontally and vertically, in the upper grades?

II. Concepts

Subject Domain	Class Concepts	Attributes
Living things	Living things:	
	characteristics	moving, breathing, eating, growing, having babies
	Animals:	
	locomotion	
	means	legs, fins, wings.
	mode	walking, swimming, flying, hopping, sliding, crawling.
	breathing	nostrils, gills.
	body covering	hairy, scaly, shell, feather, fur, skin.
	size	small/large, smaller/larger, smallest/largest.
	food	plant-eater, flesh-eater, plant and flesh eater
	habitat	in water, in air, on land, in ground.
	reproduction	born alive, hatched from an egg.
	development	larva, pupa, adult.
	Plants:	
	characteristics	not-moving (sessile)*, produce their own food (autotrophs).
	roots	going down, cylindrical, branched.
	stems	going up, cylindrical, branched.

* Technical words in parentheses will not be used in instruction.

Subject Domain	Class Concepts	Attributes
Living things (cont.)	leaves	flat, green, smooth.
	seeds	small, embryo, seed-coat.
	development	planting, watering, germination, seedling.
Non-living things	Non-living things	
	differences from living things	cannot move, breath, grow, eat, have babies.
	Objects:	
	weight	light/heavy, lighter/heavier; lightest/heaviest, equal.
	shape	spherical, cubical, cylindrical, conical, irregular.
	color	red, orange, pink, yellow, blue, white, black.
	texture	smooth, rough, soft, hard.
	Substances:	
	state	solid, liquid, gas.
	taste	sweet, salty, sour.
	odor	perfume, odorless.
	solubility	soluble/insoluble.
	Magnets	
	kinds	bar, horseshoe.
	properties	attract, repel, similar/different poles, magnetic/non-magnetic.

Subject Domain	Class Concepts	Attributes
Energy	Heat	
	sources	sun, electricity, fuel, friction.
	effects:	hot/cold, hotter/colder, hottest/coldest.
	on ice	melting, heating, boiling, vaporizing.
	on paper	burning, smoke, fire, ash.
	on wire	long/short, longer/shorter, longest/shortest, equal.
	measurement	thermometer, temperature, going up/going down.
Earth	Parts	land, water, air.
	Weather	rainy, stormy, windy, foggy, smoggy, sunny.
	Water cycle	evaporation, condensation, clouds, rain.
	Natural surface	mountainous, valley, desert, forest, ocean, lake, river.
	Constructions	tunnels, bridges, freeways, houses.
Universe	Sun	
	appearance	circular, shiny, bright, dull.
	distance	far/near, farther/nearer, farthest/nearest.
	position	horizon, east, west, north, south, right, left, overhead.
	time	day, night, morning, noon, afternoon, evening.

Subject Domain	Class Concepts	Attributes
Universe (cont.)	Moon	
	appearance	circular, full-moon, crescent, rugged.
	position	in air, in space, beyond.
	Stars	
	appearance	sparkling, twinkling.
	number	numerous/few.

APPENDIX B

ORGANIZATION OF PROPOSED SYSTEMIC CONTENT IN TERMS OF ANALYTIC CONCEPTS

BIOLOGICAL SCIENCE CONTENT

CLASS VARIABLE AND VALUE CONCEPTS

Variable name [1,2]	Values	Elements Characterized[3]
type of living thing	plant animal	examples of plants and animals
type of body covering	feathers hair scales skin (only) shell	examples of animals
type of breathing (opening)	gills nostrils	examples of animals
means of locomotion	fins legs wings	examples of animals
type of motion	walking swimming flying hopping sliding crawling	examples of animals
mode of reproduction	hatching giving "live birth"	examples of animals
type of habitat	in water on land in air in ground	examples of plants and animals

[1]Names in parentheses were not present in the original list and reflect selection of the current writer.

[2]Any class or activity concept can form the basis for a variable with values "is an x," "is not an x," or "does x," or "does not do x." Such dichotomous variables are not included in this list.

[3]If values were used to define a class, this is noted by underlining the class name.

Variable name	Values	Elements characterized
type of food eaten	flesh plant plant & flesh	examples of animals
stage of growth	larva pupa adult	examples of animals
	seed germination seedling	examples of plant plants

WHOLE-PART CONCEPTS

Complex element	Part	Function[4]
animal	body covering skin feathers scales hair fur shell	
animal	legs fins wings	moving
animal	gills nostrils	breathing
plant	roots stems leaves seeds	
seed	embryo seedcoat	

[4] The entries in this column are also activities of the complex elements. This need not be the case. More specialized functions could be specified.

ACTIVITY CONCEPTS

Activity	Elements or class characterized[5]
moving (self propelled) eating growing having babies	animals
walking swimming flying hopping sliding crawling giving birth "live" hatching	examples of animals
breathing	animals
producing own food	plants
germinating	examples of plants

DESCRIPTIVE VARIABLE AND VALUE CONCEPTS

Variable Name	Values	Elements Characterized
size	small large	seeds
shape	cylindrical flat	roots, stems, leaves
(form)	branched	roots, stems
texture	smooth	leaves
color	green	leaves
(whether living or non-living)	living non-living	animals, plants
(orientation)	going up going down	stems roots

[5]Underlined terms are classes defined in terms of the activity.

PROCESS-STAGE-EVENT-CONCEPTS

Process	Stages	Events
animal growth	larva pupa adult	
plant growth	seed seedling	germination

CLASS CONCEPTS

Class Name	Relevant variable	Class definition: Defining values
animals		moves by itself has babies breaths eats grows
plants		does not move by itself produces own food

legs
fins
wings
nostrils
gills
feathers
hair
scales
skin
shell
fur

body covering

food

Class Definition

Class name	Relevant variable	Defining values
flesh-eater plant-eater flesh and plant eater		
larva pupa adult		
stems	(orientation) shape (form)	going up cylindrical branched
roots	(orientation) shape (form)	going down cylindrical branched
leaves	shape color texture	flat green smooth
seeds	size	small
embyro seedcoat		
seedling		
babies		
habitat		
water air land ground		

PHYSICAL SCIENCE CONTENT

DESCRIPTIVE VARIABLES AND VALUES

Variable ~~Name~~	Values	Elements Described
(living or nonliving)	living nonliving	examples of objects
weight	light,-er,-est heavy, -er, -est equal	examples of objects
shape	spherical cubical cylindrical conical irregular circular cresent	examples of objects seen
color	red orange pink yellow blue white black	examples of objects
texture	smooth rough rugged	examples of objects moon
(hardness)	hard soft	examples of objects
state	solid liquid gas	examples of substances (samples)
taste	sweet salty sour	examples of substances (samples)
odor	perfume odorless	examples of substances (samples)
solubility	soluble insoluble	examples of substances (samples)

Variable Name	Values	Elements described
(magnetic characteristic)	magnetic non-magnetic	
(magnetic interaction)	attract repel	
(temperature)	hot,-er,-est cold,-er,-est	
(length)	long,-er,-est short,-er,-est	wire
(motion)	going up going down	liquid column of thermometer
(illumination)	bright dull	sun
distance	far,-ther,-thest near, -er,-est beyond	sun moon
location	in space in air	moon
number	few numerous	stars
(constancy of light)	sparkling twinkling	stars
time (of day)	day night morning noon afternoon evening	
position	east west north south right left overhead	

CLASS VARIABLE AND VALUE CONCEPTS

Variable name	Values	Elements described
(kind of magnet)	horseshoe	examples of magnets
sources of heat	sun electricity fuel friction	
kind of natural feature of earth's surface	mountain [ous] valley desert forest ocean lake river	
kind of construction (man-made feature)	tunnels bridges freeways houses	

PART-WHOLE CONCEPTS

Complex Element	Part	Characteristics or function[7]
Earth	land water air	
magnet	pole	
fire(?)[6]	smoke ash (fuel)	

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[6] The phenonenon of burning could be treated as a part-whole concept or process-stage concepts. However, the systemic concepts listed do not seem to completely fit either.

[7] It seems doubtful that the "function" of a part plays the same rule in physical science as in biological science. It seems appropriate only when dealing with mechanical devices, etc. In other cases, the term characteristics seems more applicable.

PROCESS-STAGE-EVENT CONCEPTS

Process	Stages	Events
heating	social	
		melting
	liquid	
		vaporizing (evaporating)
water cycle		
		evaporation
	cloud rain/snow	condensation
burning(?)[8]	paper	
	fire ash	(add)heat

CLASS CONCEPTS

Class name	Class description	
	Relevant variables	Defining values
non-living things		cannot move cannot grow cannot breathe cannot eat cannot have babies
object		
magnet		
fuel		

[8] The phenomenon of burning could be treated as part-whole concepts or process-stage concepts. However, the systemic concepts listed do not seem to completely fit either.

Class name	Class description: Relevant variables	Class description: Defining values
mountain valley desert forest ocean lake river		
tunnel bridge freeway house		
smoke fire ash		
cloud rain fog smog		
water		
watercycle		
ice		
liquid solid gas		
paper		
wire		
thermometer		
earth		
sun	brightness distance position	shiny, bright far (?)[9]

[9] It is not clear how the listed values are to be used.

Class name	Class description: Relevant variables	Class description: Defining values
moon	shape	circular (?) full moon crescent
	texture	rugged
	position	in space, beyond
stars	constancy of light number	twinkling, sparkling numerous

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Working Paper 4

ANALYTIC NETWORKS AND TASK DOMAINS FOR A PRIMARY GRADE SCIENCE CURRICULUM (TN 2-72-51)

Edward L. Smith

In the design of instruction, specification of desired learning outcomes can be viewed as having two interrelated aspects: structural and operational. The structural aspect refers to relevant subject matter content and its logical structure, while the operational aspect refers to what the learner does with that content. This paper discusses the relation between these two aspects, describes various levels of analysis for each aspect, and finally presents structural and operational specifications for a science component of a primary grade curriculum. These specifications define a domain within which detailed skills analyses and empirical investigations of instructional problems can be carried out. A central assumption underlying the current analysis is that appropriate coordination of the structural and operational aspects of learning outcomes can result in the development of skills with considerable generality and transfer potential.

STRUCTURAL AND OPERATIONAL ASPECTS OF INSTRUCTIONAL OUTCOMES

In a previous paper (Smith, 1972) three levels of analysis were proposed for describing the structural aspect of instructional outcomes. At the *systemic* level, specialized concepts of discipline or subdiscipline are specified (e.g., weight, cost, mammal, and electron). The *analytic* level represents an abstraction of the logical structure of the systemic content. Each systemic concept is an example of some analytic concept (e.g., "weight" is an example of a "variable name," while "mammal" is an example of a "class name"). Finally, the *particular* content involves the specific materials, events and so on which are used to exemplify the systemic content (e.g., "mammal" might be exemplified by pictures of lions, horses, elephants, and people).

Specification of content at these three levels does not, by itself, define the operational aspect of an instructional component; that is, what the learner should be able to *do* with that content. However, the structure of content as reflected by networks or related analytic concepts has definite implications for operations appropriate to the content.

For example, the variable-value analytic network includes the following components:

elements -	The phenomena to be described, compared, related or otherwise studied (e.g., objects, events, systems, and sets).
variable name -	The name of an aspect or dimension on which elements may differ (e.g., color, weight, and cost).
values -	The terms, numerals or other symbols available for assignment to elements for a variable (e.g., red, four pounds, fifty cents).
observation/measurement - procedure	The standard procedures or algorithms used to assign values of a variable to particular elements (e.g., use of a centigrade thermometer for determining temperatures).

Conceptual systems exemplifying the structure represented by the variable-value network are amenable to operational requirements which reflect that structure. The kinds of information which serve as input and output for a given operational requirement can be classified in terms of analytic concepts. A description of an operational requirement with the input/output relations defined in terms of analytic concepts is called a task description. For example, one task can be described as follows: *carry out an observation/measurement procedure to determine which value of a named variable accurately describes a given element.* The input for the task is an *element* and a *variable name*. The output is an *observation/measurement procedure* and a *value*.

By selecting systemic and particular content, and by specifying the instructions, an *item* exemplifying a given task may be constructed. For example, one item can be formed by selecting weight as the variable and a particular sea shell as the element, and by specifying the instruction as, "Determine the weight of this object." Although access to any needed equipment would have to be made available, no direction to that equipment would be given since the task does not specify the observation/measurement procedure as input. It must be provided by the individual performing the task. Clearly the task represents a large number of items differing as to the variable name, the object, and the instruction as well as the details of the general context. At the analytic level, however, these items share a common structure.

Beyond their use in describing existing items, the components of an analytic network define the kinds of information or actions which can potentially serve as input and output in items. Thus, any two subsets of components of a network are suggestive of a potentially important task. The definitions of the components can be used to interpret input-output combinations as tasks which are meaningful for that network. For example the input-output combination

input: variable name
output: value

is meaningfully interpreted as supplying values conventionally associated with the given variable name. Once a task has been defined for an analytic network, it identifies an operational requirement appropriate to any conceptual system exemplifying that analytic network. The task then provides the basis for generating items.

The specification of a task does not indicate the information processing strategies, perceptual-motor performances, or other skill components by which items exemplifying that task might be carried out. However, the probability of payoff from detailed behavioral analyses is greatly increased by prior selection of important tasks constructed from analytic networks which span large domains of systemic and particular content. If a large number of systemic examples of the analytic concepts exist, then tasks described in terms of those concepts necessarily have an equally large number of potential applications. If behavioral analysis of possible modes of performance in several applications of a task reveals similar skill components, the generality and relevance of the skills selected for training will be assured.

From the point-of-view described above, the initial specification of the structural and operational aspects of the outcomes for an instructional component should be in terms of analytic networks and associated task domains, respectively. These initial specifications may be revised in light of the results of subsequent behavioral analysis and empirical studies of learning and performance on items for specific tasks. However, such specifications define a restricted domain within which further detailed analyses may be carried out.

ANALYTIC NETWORKS FOR USE IN INSTRUCTIONAL DESIGN FOR SCIENCE INQUIRY OUTCOMES IN A PRIMARY GRADE CURRICULUM

Several analytic networks have been identified which characterize the structure of much science content in existing primary science programs (Smith, 1972). Three analytic networks were selected as a basis for instructional design work: the variable-value network, the class-member network, and the intra-element relation network.

As defined above, the variable-value network is built on the idea of primitive entities or *elements*. When these entities are described, compared or otherwise studied, only certain aspects of them are considered. These aspects are characterized in terms of *values* for dimensions or *variables*. Each variable is associated with one or more observation/measurement procedures.

The class member network is built upon the variable-value network. This relationship is reflected in the following definitions for the analytic concepts comprising the class-member network.

class -	A designated set of elements (e.g., the set of zebras).
class member -	An element which is in a class (e.g., a particular zebra).

class rule -	A decision rule by which it may be determined whether or not an element is a member of a class, consisting of values and logical connectives (e.g., an animal which has four legs, black and white stripes, etc.)
class name -	Name applied to an element as a consequence of its membership in a specific class (e.g., "zebra").
defining value - (for a class)	A value employed in a class rule (e.g., four legged).
relevant variable - (for a class or set of classes)	A variable whose values are employed in the rule for a class or in the rules for a set of classes (e.g., number of legs).
partition -	A set of mutually exclusive (pairwise disjoint) classes constituting a superordinate class (e.g., the set of animal species).
partition name -	A term or phrase referring to a specific partition, that is, to a specific set of mutually exclusive subclasses of a specific superordinate class (e.g., "species of animal").

Although some classes may be adequately dealt with in isolation, most seem to require the context of a system of related classes. For this reason, the last two analytic concepts were included from the outset.

The third analytic network selected was the intra-element relations network. Intra-element relational rules specify a relation between an element's membership in one class and its membership in another class defined in terms of different relevant variables.[1] Thus, these rules

[1]Simple taxonomic hierarchies which simply add further defining values to the class rules are not included here. Such relations can be derived directly from the class rules. This is not the case for intra-element relations.

relate one set of characteristics of an element (those specified by the rule for one class) to another set of characteristics for the same element (those specified by the rule for the second class).[2] For example, the relational rule "clay soils have a large water holding capacity," relates the defining values of clay soils (i.e., their particle size and chemical composition) to a value (large) for a different variable (water holding capacity). Typically, many intra-element relations are expressed in terms of the classes of important partitions of the element studied in a given discipline. Agronomists use many relations, such as the above example, involving the composition partition and the water holding capacity partition of soils.

In addition to the components of the class-member network, the following are components of the intra-element relations network:

intra-element relation -	A relation between membership in one class and membership in another class, i.e., between the corresponding sets of defining values (e.g., class inclusion).
intra-element relational rule -	A rule specifying an intra-element relation between two classes (e.g., "clay soils have a large water holding capacity").
related classes -	An ordered pair of classes defined by different relevant variables, and between which an intra-element relation holds (e.g., clay soils and soils with high water holding capacity).

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[2]In the limiting case, the rule merely relates a value of a single variable to a value of another variable for a set of elements. When a value of a single variable occurs in an intra-element relational rule, it will be treated as a class rule with a single defining value.

related partitions - Two partitions of a superordinate class which are defined on different relevant variables, such that at least one class of one partition is related to at least one class of the other (e.g., the soil composition partition and the soil water capacity partition).

There were several reasons for selecting these networks. The first was the scope of their applications. Each was found to reflect the structure of a considerable portion of the systemic and particular content of extant primary science programs (Smith & McClain, 1972; McClain, 1972). Further support for their generality is provided by the attention given to analytic concepts from these networks by philosophers of science.

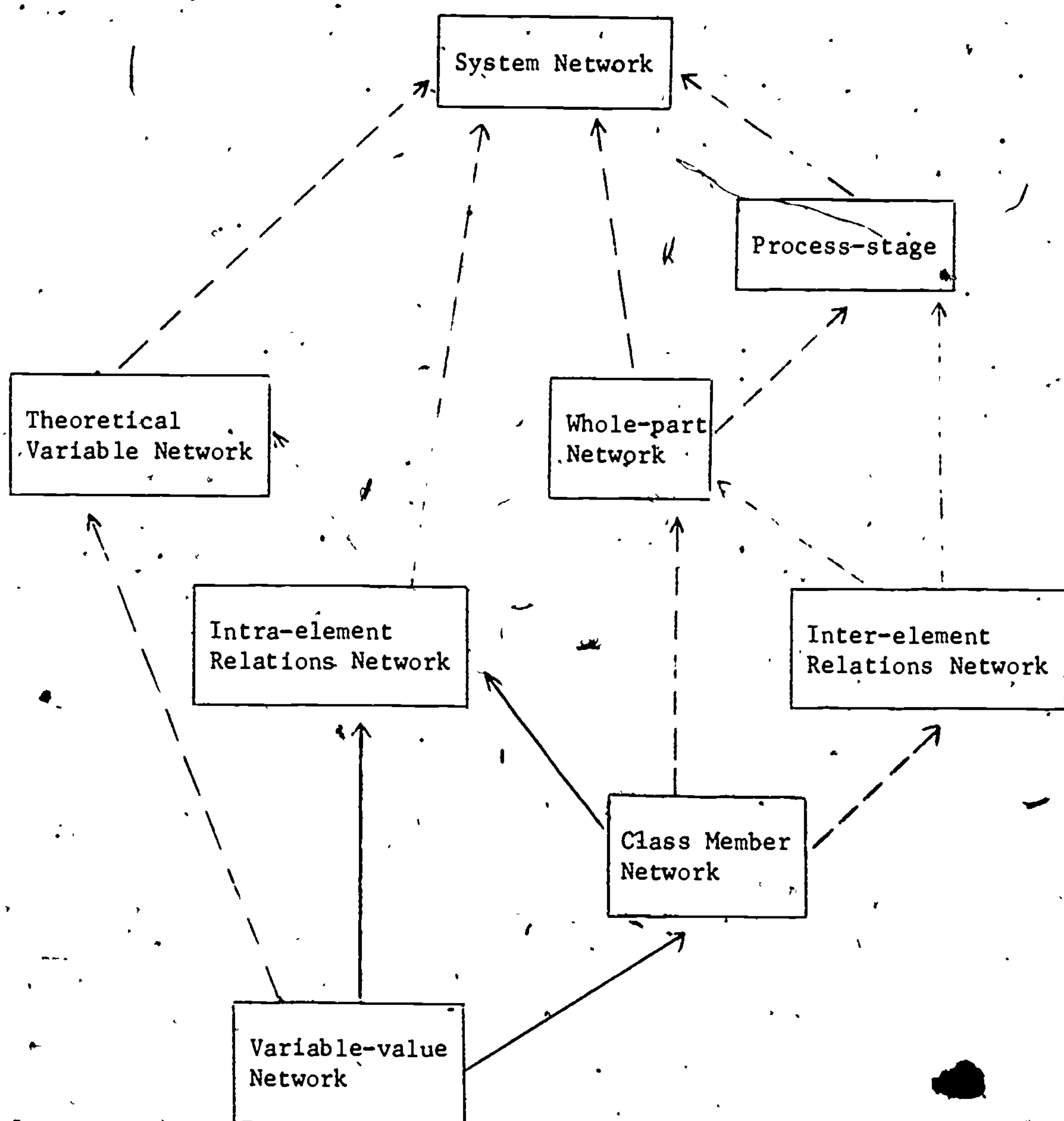
Second, these three networks are interrelated in a fundamental way. The variable-value network provides a foundation for the class-member network while both of these underlie the relational network (see Figure 1). Although it might not be necessary to carry the analyses through to the relational level for the primary curriculum, it is that level at which the power and utility of the variable-value and class-member networks are revealed. An analysis of the variable-value or class-member networks in isolation might fail to provide an adequate basis for the relational network. Further, it is quite likely that instruction which reaches the relational level rather quickly will prove more highly motivating than that which deals extensively with the lower level networks in isolation. The interdependence also means that considerable practice with the lower level networks will be obtained in the context of use of the higher level ones. This should promote consolidation and retention of earlier learning.

A third reason for these selections is the foundation they provide for other networks. Some of the networks which might be built upon this foundation are also indicated in Figure 1. The class-member network is a basis for inter-element relations, those in which a member of one class is related in a specified way to a different element in another class (e.g., hydra prey upon daphnea). A specialized intra-element relation, the whole-part relation, is broadly applied in the biological sciences and forms the basis of a network involving the function of the part in relation to the activity of the whole. This network would probably provide a point of departure for a systems network. The variable-value, class-member and part-whole networks lead into the process-stage network.

The variable-value network, based on empirical variables, and the intra-element relations network provides a foundation for a theoretical variable network to cover variables defined only in terms of other variables (e.g., energy). With the addition of the theoretical variable network, the power of the systems network would be considerably increased.

SCIENCE TASK DOMAINS

The analytic networks described above represent criteria for the structural aspect of science outcomes for the primary curriculum. That is, they prescribe the kinds of concepts and conceptual systems with which children will learn to function. As discussed above, the



Key: ⟶ relations already analyzed
----> anticipated relations

Figure 1. Interrelations among analytic networks.

selection of analytic networks puts constraints on and is suggestive of the operational aspect of the outcomes. Specifications of the operational aspect take the form of tasks defined for each analytic network.

Several methods were employed in obtaining tasks for the selected analytic networks. One method was the review and analysis of relevant literature and materials. One source was extant instructional programs which involve systemic content exemplifying the analytic networks (McClain & Smith, 1970). Another source was psychological and educational literature related to the kinds of concepts included in the network (Bruner et al., 1956; Inhelder & Piaget, 1964). The performance requirements from these sources were described in terms of the analytic networks to produce potentially useful tasks.

A second method made systematic use of the components of the network in generating new tasks. Since the components represent information or action which can serve as input or output, any two subsets of components represent the basis of a potentially useful task. Not all such combinations result in meaningful tasks, however. Judgement is required in applying the defined relations among the components of the network in the interpretation of combinations as tasks.

By taking all possible combinations of components, many tasks can be generated and a degree of completeness can be assured. Such a comprehensive analysis establishes a domain of alternatives for the operational aspect of instructional outcomes and thus defines the decisions that must be made. A domain of alternatives also allows a determination of the representativeness of any given subset of tasks. Selection of a representative sample of tasks increases the probability of identifying generalizable strategies and other skills.

In addition to the judgement involved in interpreting the combinations of components as tasks, decisions are required in selecting from among the large number of tasks generated. Skill analysis will provide the basis for many such decisions. However, some initial selection of tasks which will define terminal outcomes for an instructional component is required. Ideally, these selections would be made on the basis of analyses of the requirements likely to be made of the child in later instruction, and in his everyday life in both the immediate and distant future. Such analyses are not currently available, however, and may not even be possible at the present time. Thus, the selections represented by the tasks specified below represent professional judgement. It should be recalled that these selections were not made in isolation, however. They were made after the careful selection of analytic networks which appear to have broad generality, and against the background of relatively comprehensive domains of tasks for each network.

The exercise of professional judgement in the selection of tasks involved the application of the following criteria:

1) Does it represent acceptable scientific inquiry?

2) Does it have informative value for the performer?

3) Is it relevant to higher level networks?

4) Is it amenable to strategies useful to primary school children?

5) Is it amenable to strategies applicable to the tasks selected from the other networks?

First priority was given to tasks which appeared to meet both the relevance and the hierarchical criteria. Second priority was given to tasks which met only the hierarchical criteria. Tasks which met only the relevance criteria were selected only when a network was not adequately represented otherwise.

TASK DOMAIN FOR THE VARIABLE-VALUE NETWORK

The task domain for the variable-value network is divided into four subclasses: simple description, qualitative comparison, seriation, and sorting tasks. Only the components of the variable-value network may serve as input and output. Although items for these tasks may involve more than one variable (e.g., a description on several variables), no class rules are involved.

Simple Description Tasks

Simple description tasks involve elements, values and observation/measurement procedures. They may involve variable names. These tasks deal with element-value relations, but not with element-element or value-value relations.

Three simple description tasks were selected for specifying science outcomes for the primary curriculum (see Table 1). The nondirected task represents a relatively high level of independent inquiry. It also requires the recall and selection of variables, an important skill

TABLE 1

SIMPLE DESCRIPTION TASKS

Task Name	Given Input	Required Output	Sample Item
Element Identification	a set of elements a value for a variable	an observation/measurement procedure for the variable an element described by the given value	Given samples of salt, sugar, flour, sand, and chalk. "Determine which substance is soluble in water."
Directed Description	an element a variable name	an observation/measurement procedure for the named variable a value for the named variable which describes the given element	Given a mineral specimen. "Determine and report the hardness of this rock."
Nondirected Description	an element	an observation/measurement procedure for a variable a value describing the given element on that variable (multiple cycles may be required)	Given a leaf specimen. "Describe this leaf as completely as you can."

component in many higher level tasks. The directed description task requires a response to a variable name as do many higher level tasks. The element identification task frequently occurs in a variety of classroom situations, and involves skill components common to many higher level tasks, namely value decoding and some type of search strategy.

Comparison Tasks

Comparison tasks involve relations between two or more elements with respect to a specific variable. The values assigned to elements as a result of comparisons refer to the relation between that element and a specific set of other elements. These relations may be qualitative (specifying only same-different judgements), or quantitative (specifying an amount). Quantitative relations can be further subdivided into ordinal, interval and ratio relations. Only qualitative and ordinal quantitative relations will be considered further at this time. For simplicity, values referring to qualitative relations will be called *comparative values* (e.g., some, different). Those referring to ordinal relations will be called *ordinal values* (e.g., hotter, more dense, first, third). It should be noted that the applicability of comparative or ordinal values to an element is dependent, by definition, on the set of elements with which that element is compared. Comparison tasks therefore involve the specification of a set of elements as a given input or required output.

Two classes of comparison tasks have been defined, corresponding to the two types of values: comparative tasks and seriation tasks. The *comparative tasks* selected for the primary curriculum are listed in Table 2. The non-directed comparison task represents a relatively high level of independent inquiry. It also appears to be a satisfactory vehicle for building skills required for sorting tasks. The subset formation task was selected, somewhat arbitrarily, for its contribution of skills While the non-directed comparison task involves recognition and description of relations between a given set of elements, the subset selection task requires the formation of a subset of elements meeting specified comparative criteria. The directed comparison task is included here because it provides a vehicle for skills required for response to variable names. These skills are required in many higher level tasks where variable names serve as input or mediating responses.

The selected seriation tasks are listed in Table 3. The non-directed seriation task was selected because of the relatively high level of independent inquiry it represents and because it appears to incorporate skills important in the discovery of relations between variables. Another seriation task also appears to incorporate skills important to such discoveries, namely, the seriation variable identification task. The directed seriation task was included as a vehicle for the skills required in responding to variable names.

Sorting Tasks

Sorting tasks involve subsets of elements formed on the bases of similarity on a specific variable. The sorting tasks selected are

TABLE 2

COMPARATIVE TASKS

Task Name	Given Input	Required Output	Sample Item
Comparison Variable Identification	a set of elements a comparative value	the name of a variable for which the given comparative value characterizes the relation between the given elements (multiple cycles may be required)	Given a bean plant, a corn plant and a cactus. "In what ways are these plants the same?" (e.g., color, means of attachment)
Directed Comparison	a set of elements a variable name	the comparative value characterizing the relation between the given elements on the named variable	Given a bean leaf and a corn leaf. "Compare the shapes of these leaves." (e.g., different)
Nondirected Comparison	a set of elements	a variable name the comparative value characterizing the relation between the given elements on the named variable. (multiple cycles may be required)	Given a mouse, a frog, and a lizard. "Compare these animals." (e.g., same number of legs, different body covering)
Subset Formation	a set of elements a variable name a comparative value	a subset of elements such that the relation between them on the named variable is characterized by the given comparative value	Given specimens of teeth from a cow, a man, a dog, and a rat. "Pick out some teeth which have the same shape." (e.g., the double molars)

TABLE 3

SERIATION TASKS

Task Name	Given Input	Required Output*	Sample Item
Seriation Variable Identification	a set of elements ordered such that their order corresponds to their order on a variable	the name of the variable on which the elements are ordered	Given a set of plants ordered by height. "Why were these plants placed in this order?"
Directed Seriation	a set of elements a variable name	the set of elements ordered on the named variable	Given a set of mineral samples. "Place these samples in order according to their hardness."
Nondirected Seriation	a set of elements	the set of elements ordered on a variable	Given a set of corn seedlings. "Show a way that these seedlings differ by placing them in order."

*An observation/measurement procedure is required output for each task.

listed in Table 4. These selections parallel those for the seriation tasks. The non-directed sorting task stands on its own as an inquiry task while both the non-directed sorting and the sorting variable identification tasks provide vehicles for skills useful in discovering relations among variables. The directed sorting task is included to assure that sorting on a specific variable can be brought about through the use of the variable name.

THE TASK DOMAIN FOR THE CLASS-MEMBER NETWORK

Tasks for the class-member network involve class rules by which the applicability of a class name to an element may be determined. Several classes of tasks have been distinguished. Element classification requires some identification of class membership for a given element or elements. Member specification tasks provide information identifying a class, but require specification of elements which are members. Both of these task classes presuppose that a class rule is known by or presented to the individual performing the task. The third task class involves inferring a class rule. Elements, or description of them, and information as to whether or not they are members are provided as input, while a class rule accounting for the membership information is required as output.

Tasks from each of the above classes were selected (see Table 5). Three element classification tasks were selected. The non-directed classification task stands by itself as relatively independent inquiry while directed classification and partition identification provide

TABLE 4

SORTING TASKS

Task Name	Given Input	Required Output*	Sample Items
Nondirected Sorting	a set of elements	the set sorted into subsets on a specific variable	Given samples of liquids differing in color, viscosity and opacity. "Sort these substances into groups on one variable."
Sorting Variable Identification	a set of elements sorted into subsets on a specific variable	the name of the variable on which the elements are sorted	Given drawings of irregular polygons differing in area and number of sides, sorted by number of sides. "How have these figures been sorted?"
Directed Sorting	a set of elements a variable name	the set sorted into subsets on the named variable	Given a set of small common objects and access (but not direction) to a container and water. "Sort these objects by their buoyancy."

*An observation/measurement procedure is required output for each task.

TABLE 5

CLASSIFICATION TASKS

Task Name	Given Input	Required Output	Sample Items
ELEMENT CLASSIFICATION			
Nondirected Classification	a set of elements	subsets of elements by classes of a partition class name for each subset	Given pictures of mountains, deserts, valleys, etc. "Classify these pictures by placing them in groups. Give a name for each class."
Directed Classification	an element a partition name	the name of the class of the name partition of which the element is a member	Given a picture of a rocky inter-tidal zone area at low tide. "Name the class of habitat shown in the picture."
MEMBER SPECIFICATION			
Member Selection	a set of elements	the element(s) which is (are) a member of the named class	Given pictures of rain, sleet, snow, and fog. "Which picture shows sleet?"
Rule Application	a set of elements a class rule a class name	the element(s) which is a member of the named class	Given pictures of cirrus, stratus, and cumulus clouds. "Cirrus clouds are feathery looking and occur only at high altitudes. Which pictures show cirrus clouds?"

Task Name	Given Input	Required Output	Sample Items
Partition Identification	subsets of elements by the classes of a partition	the name of the partition or class names for each subset	Given subsets of pictures of reptiles, mammals, amphibians and birds. "These animals have been classified by placing them in groups. Tell how they were classified."
Rule Inference	element designated as a member(s) or nonmember(s) of a novel class the class name	a class rule which accounts for the given class membership information	Given samples of igneous, metamorphic and sedimentary rocks. "These (point to igneous rocks) are igneous rocks. These others (point to others) are not. Give a rule for classifying igneous rocks."

vehicles for additional skills. Two member specification tasks were selected. Member selection requires the individual to supply the class rule and represents a frequently occurring classroom task. The rule application task provides a rule. The skills involved in this task relate to comprehension of new verbal information. The rule inference task is a version of the concept acquisition task widely thought to typify informal or contextual learning.

THE TASK DOMAIN FOR THE INTRA-ELEMENT RELATION NETWORK

Tasks selected for the intra-element relations domain represent somewhat arbitrary selection from each of four task classes. Rule application tasks provide a relational rule as input. The selected rule application task (see Table 6) also provides the name of one of the related classes and a set of elements including members and non-members of the named class. The elements must be presented such that membership in the named class cannot be determined by use of the class rule for that class. The required output includes specification of members and non-members of the named class.

Prediction and explanation tasks require a familiar relational rule and class name as output. The selected prediction task provides a partition name as input while the explanation task provides the name of one of the related classes. The fourth class of tasks, rule discovery, requires a novel relational rule as output. The selected rule discovery task provides a set of elements for which a relation holds between

TABLE 6

INTRA-ELEMENT RELATION TASKS

Task Name	Given Input	Required Output	Sample Items
Relational Rule Application	a rule relating membership in two familiar classes the name of one of the related classes a set of elements (presented so that membership in the named class is not directly observable)	specification of those elements which are members of the named class	Given pictures of common wild birds. "Birds with short, pointed bills are usually seed eaters. Which of these birds probably eat seeds?"
Prediction	the name of a partition an element (presented so that its membership in classes of the named partition cannot be directly observed)	the name of the class of the named partition of which the given element is a member	Given a picture of a sea turtle. "In what kind of location would this animal lay its eggs?"
Explanation	a class name an element which is a member of the named class	the name of a related class of which the element is observed to be a member a rule relating membership in the two classes	Given a fish (with observable gills). "How can you tell that this animal lives in water?"

Task Name	Given Input	Required Output	Sample Items
Rule Discovery	a set of elements for which a relation holds between membership in two familiar classes the names of the related partitions	a rule relating membership in the two classes	Given a set of stunted (small) corn plants growing in limited light, and a set of normal (large) corn plants growing in bright light. "What relation can you find between the amount of light and the size of the plants?"

membership in two familiar classes, and the names of the partitions of which the related classes are constituents.

The relational rule application task provides a vehicle for skills involved in comprehending and utilizing rules from secondary sources as in problem solving. The other three tasks represent relatively independent inquiry for primary children while providing a context for development of skills required for higher level inquiry tasks.

DISCUSSION

The relation between task analysis and behavioral analysis of performance requirements for given tasks was mentioned above. As stated by Klahr and Wallace (1970, p. 360), "The objective task structure alone does not yield a valid description of the solution performance, and it is necessary to diagnose the actual psychological processes in great detail to obtain minute descriptions or well supported inferences about the actual sequence and content of the thinking process." However, the resource requirements for such analysis are so great that considerable care must be taken to maximize the probability that generalizable strategies and skills will be identified. Procedures have been described above for structural analyses of content in terms of analytic networks and operational analysis in terms of tasks. These procedures provide a means of defining a greatly restricted domain for behavioral analysis, a domain with considerable potential for the identification of broadly generalizable strategies and skills. Where the time line for program development precludes extensive skills analysis, the procedures provide a means of generating and describing potential outcomes which reflect the logical structure of relevant conceptual systems.

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Working Paper 5

A SKILLS ANALYSIS OF SELECTED PRIMARY LEVEL SCIENCE TASKS (TN 2-72-60)

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An analysis of scientific inquiry behavior for constructing a primary level science progarm could be carried out in many ways and at many levels. One could examine the behavior of mature scientists, teach games which mimic experimental procedures, analyze traditional topics such as deduction and induction, examine the strategies of children, or conduct studies to optimize commonly used science instructional techniques. Rather than proposing extensive behavioral analyses or reworking old instructional solutions, we have concentrated on identifying frequently occurring classes of concepts (content analysis), specifying tasks relevant to those classes of concepts (task analysis), and describing solution alternatives for those tasks in the form of flowcharts.

If these solution alternatives are adequate, then the flowcharts specify what must be learned in order to carry out certain kinds of scientific inquiry. The flowcharts are not general models of children's thinking or descriptions of how children typically perform the tasks. Rather, they are descriptions of supposed minimal cognitive events by which the tasks might be successfully executed. The capability of carrying out these events represents possession of "inquiry skills." The development of such capabilities or skills is the goal of instruction in scientific inquiry. The preparation of descriptions of them is the main function of skills analysis. Appropriate sequencing and instructional procedures remain to be specified.

The distinctions between the different levels of analysis of performance that we distinguish are illustrated with the following example (see Figure 1). A child is presented with a set of six corn seedlings (A-F) growing in similar containers, and is instructed to "order them according to their height" (see Figure 1a). After a quick visual scanning of all the plants, the child selects two (C and E), places them next to one another, and looks at them. He then selects a third (A) and places it, in turn, in front of each of the first two. He then adjusts the first two making room to place the third between them. The three are properly ordered in height, (see Figure 1c). The next plant selected (D) is somewhat shorter than the others. The child places it in line next to the shortest of the ordered plants and, after looking at both, selects another new plant (F). The child first places this plant in front of the next-to-the-tallest plant (A). The new plant is shorter. He then places it in front of the next shorter plant (E). After looking at those two plants, he places the new one between the two with which he had compared it (see Figure 1e). He then takes the sixth plant (B) and places it in front of the next-to-the-smallest plant in the row (E) and looks at them. The new plant is taller. He moves the plant to the next taller plant in the row. This plant is very nearly the same height as the new one. After looking back and forth for some time, the child adjusts the new plant so it is directly in front of the plant in similar height. After looking around the table, the child turns and, with a shrug and a sigh, says "There!".

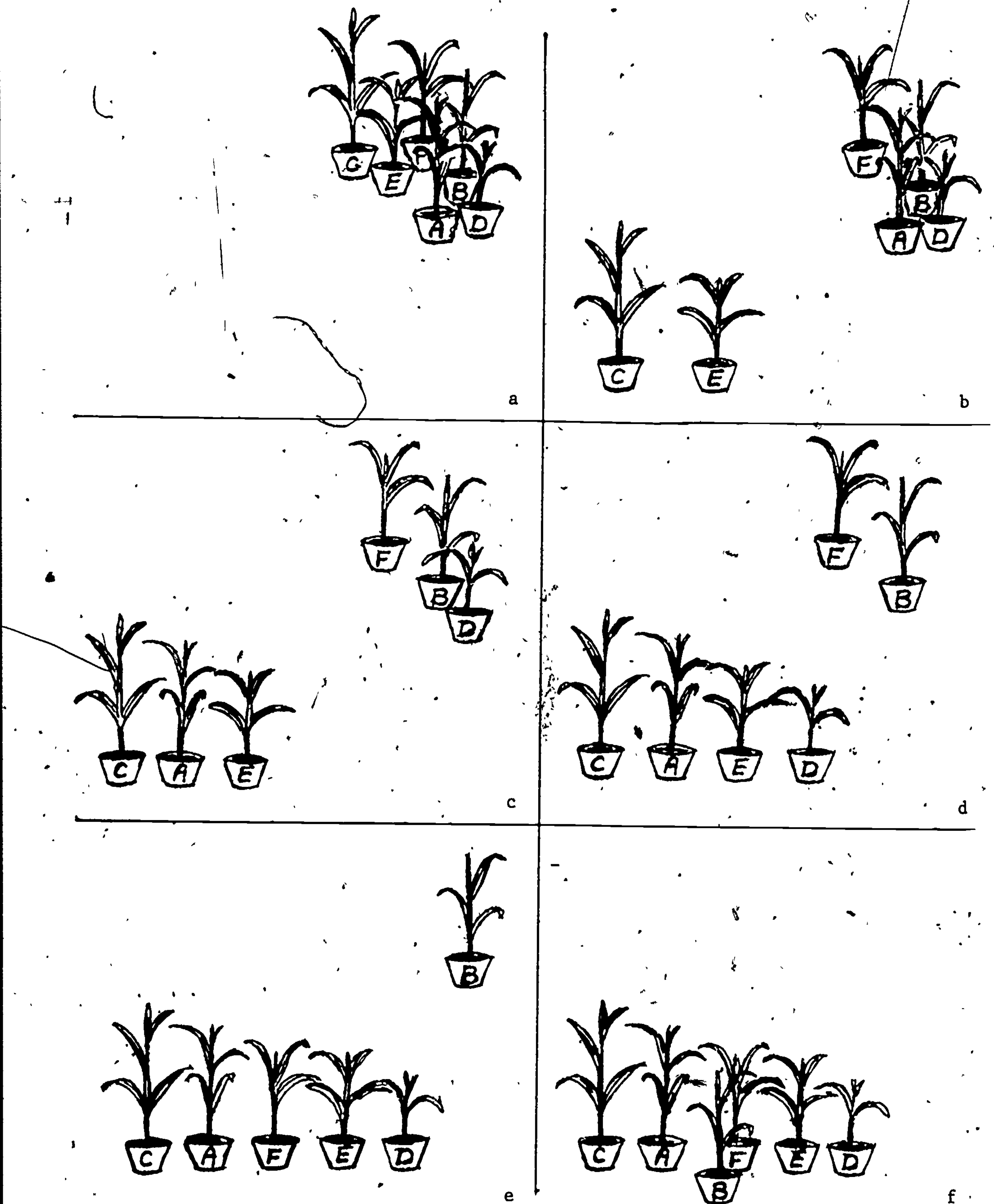
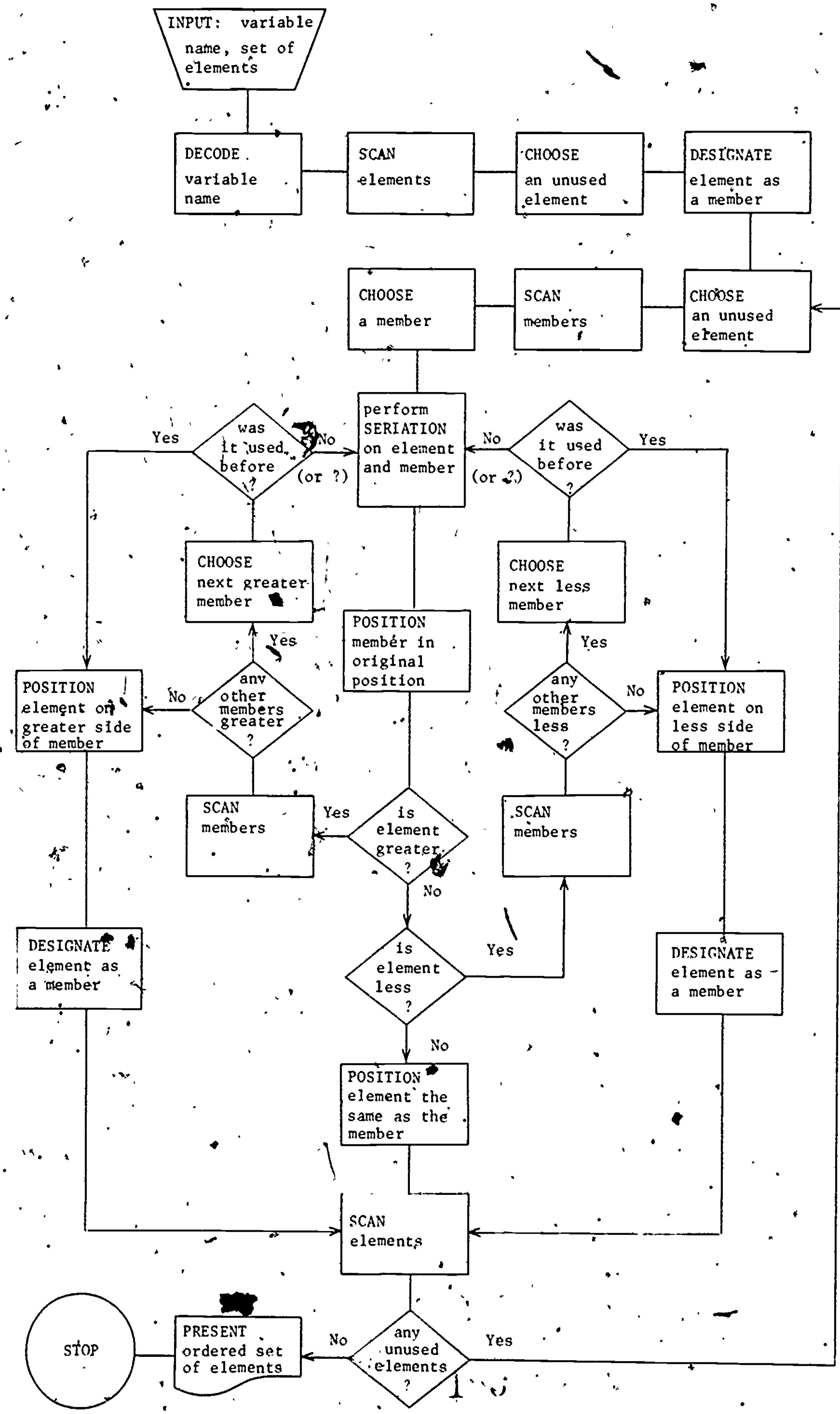


Figure 1. Stages in the performance of an ordering task in which corn plants are ordered on height.

The performance described above can be analyzed at three levels. The task, described apart from the content, was to produce a set of elements ordered on a variable given the unordered elements and the name of the variable. The content involved included the "height" conceptual system and the corn plants with their respective heights.

Important skills involved in the performance of the task are identified in the diagram in Figure 2. The boxes represent hypothesized individual processing steps required for performance. These include decoding of verbal input, visual scanning and search, retrieving of information from long-term memory, utilizing spatial position to represent order, and others. These processes are described in more detail in a later section of this paper. The sequence of processing steps, on the other hand, represents an inferred strategy for carrying out the performance utilizing the component processes. The strategy is analogous to a computer program which the individual constructs, largely from stored information, in order to perform.

Execution of the illustrated strategy represents one relatively efficient and effective means for carrying out the task on any appropriate content. The strategy results in constructing a spatially ordered subset which, no matter how many elements remain to be ordered, is properly ordered on the ordering variable. Further, only one new element is introduced at a time. These features result in a minimum memory load. The strategy allows educated guesses as to where in the sequence a new element will fall without resulting in erroneous ordering if the guess is inaccurate. This allows reasonably efficient performance without high risk of error.


INPUT: variable name, set of elements
DECODE variable name
SCAN elements
CHOOSE an unused element
DESIGNATE element as a member
CHOOSE an unused element
SCAN members
CHOOSE a member
perform SERIATION on element and member
was it used before ?
Yes
No
(or ?)
was it used before ?
No
Yes
(or ?)
CHOOSE next greater member
CHOOSE next less member
POSITION member in original position
Yes
Yes
any other members greater ?
No
POSITION element on greater side of member
any other members less ?
No
POSITION element on less side of member
SCAN members
Yes
is element greater ?
No
SCAN members
DESIGNATE element as a member
is element less ?
Yes
DESIGNATE element as a member
No
POSITION element the same as the member
SCAN elements
STOP
PRESENT ordered set of elements
No
any unused elements ?
Yes

The processing routine illustrated above, and the others reported in the present paper, were devised as reasonably simple, efficient, and reliable approaches for carrying out the respective tasks. They do not represent inferences as to how children (or adults) typically do perform the task. Rather, they represent a preliminary specification of how children might perform the tasks following appropriate instruction. As such, they are subject to modification on the basis of empirical studies.

FUNDAMENTAL PROCESSES INVOLVED IN THE ROUTINES

Analysis of the skills with which a specific task may be performed involves the specification of a sequence of processing steps. A particular processing step is described as acting upon certain input information by transforming it or using it to obtain other information. The output of the step is the new or transformed information. In specifying a processing step for a given task, the kind of process involved is identified by naming a fundamental process whose general nature has been previously described elsewhere. The descriptions of these fundamental processes represent hypotheses based on current psychological knowledge. Fundamental processes are further divided into primary, secondary and tertiary processes. A processing step involving a primary process represents what, for purposes of the analysis, at least, is considered to be a unitary skill, e.g., decoding a variable name (e.g., "height") in Figure 2. Secondary processes are frequently recurring sequences of primary processing steps, e.g., the SERIATION process in Figure 2. Tertiary processes may be defined in terms of both primary and secondary processes.

The coordination of a set of processing steps into a functioning system represents a skill of a different type. Such coordinating or directing skills will be referred to as strategies. They can be thought of as control programs which call upon the fundamental processes as needed. An individual who had acquired the strategy described in the flowchart in Figure 2 would perform the seriation task in a manner such as presented in the above example. In the following sections, fundamental processes are defined and briefly discussed in terms of the theoretical points-of-view they reflect.

PRIMARY PROCESSES RELATED TO LONG TERM MEMORY

Several processes involve gaining access to information available in the individual's long-term memory. The demands made on a model of long term memory in defining the primary processes include specification of the nature of the information stored, the kinds of information which can be used to gain access to stored information, and the major processing steps distinguished.

Frijda (1972) describes a model of long-term memory, some version of which is utilized in nearly all information processing theories and simulations. According to this view, information stored is an associative network of items or nodes, each leading to any number of other nodes—the associations of the first node. The stored items or nodes are generally considered to be concepts or ideas themselves rather than names used to refer to them or images exemplifying them. Although this is a somewhat vague position, the important point seems to be that what is stored is not words or images but rather information from which words, images and actions are reconstructed, as proposed by Neisser (1967). Thus, once activated or accessed, a node makes immediately available a number of operational options. Nodes are accessible by way of other nodes to which they are linked, by way of items or stimuli that in some sense resemble them (i.e., that resemble some level of reconstruction), or through the decoding of labels that refer to them.

DECODE

This is the primary process by which an associative network is entered by way of a verbal label for one of the constituent concepts. The input for the process is the verbal label. Decoding of the label results in the activation of a concept or node in the network. This does not necessarily result in the reconstruction of images, actions, or verbal entities. In effect, the DECODE process opens the way to many possibilities, but it remains for the next step(s) to take advantage of one or more of them. The possibility that the individual is set to perform another step which then follows automatically from the decoding need not concern us here. The point is that access to the storage network must be gained as a result of processing the verbal label. This is the function of the DECODE process.

RETRIEVE

Once a node in an associative network has been activated, e.g., by DECODE, access is gained to other nodes in that network. However, some directing process insures that the appropriate node(s) is activated next. This involves the RETRIEVE primary process. The nature of this directing mechanism is not further elaborated here.

At present it seems sufficient to say that it is capable of directing the RETRIEVE process to a connected node which is related to the original node in a specific way. Thus, the input of RETRIEVE can be characterized as one concept and its output as another. Just as was the case with DECODE, RETRIEVE does not output any images, words or actions although it does make such further steps an immediately available option. RETRIEVE can usually avoid retrieving a recently retrieved node through short term recall of associated information. This allows the process to recycle efficiently until appropriate information is obtained.

INPUT STIMULUS ANALYZING PRIMARY PROCESSES

Several primary processes are defined which seek and analyze input. Input is viewed as containing an enormous amount of information, only a portion of which is attended to or detected by the individual on a given occasion. Analysis of the input is viewed as taking place at different levels, each level involving its own unique kind of processing. Preattentive processes have a large capacity for parallel activity. They construct perceptual "objects" in a figure-ground differentiation sense. These processes are limited, however, in the level of detail and precision they represent. Basically, they signal when more detailed analysis of particular input by other processes is warranted. The higher level processes which require attention are linear. They construct detailed images and are more selective.

SCAN

This is a primary process which represents a rather cursory, largely visual, exploration of the stimulus field. It establishes a figure-ground differentiation of objects and detects a few salient features which may enter short-term store. However, only partial information is obtained, even in the visual modality. Detection of certain salient and/or relevant features usually terminates the SCAN process, or at least relegates it to a background role, and triggers some attentive processing. Thus, the input to SCAN is undifferentiated stimulus information while the output is one or more differentiated perceptual objects. In most cases, many features which are relevant from a formal point-of-view are not detected by SCAN.

CHOOSE

This is a primary process which operates on a set of stimulus objects previously differentiated, e.g., by SCAN. The output is one object which then becomes the focus of attention. The criteria for this selection are not formal. Rather, such factors as visual accessibility, proximity to the observer, and the relative saliency of detected features are employed. From a formal point-of-view, the process is essentially a random selection. One exception is that CHOOSE can usually avoid selecting previously chosen objects by utilizing feature information stored in short-term memory. This information may well be otherwise irrelevant to the task at hand.

ACT

This is the process of acting on an object in such a manner as to obtain a particular kind of input (e.g., color or temperature information). This might involve orientation of the required organs, exploratory movements such as visual scanning or tactile exploration, and/or manipulation of objects such as hefting or squeezing. Performance of ACT requires a prior retrieval of the appropriate action from long-term memory, i.e., activation of the observation action node in an associative network. This activation makes available the information from which a control program can be reconstructed. For present purposes, no distinction will be made between the construction and execution of the program and ACT will be treated as a primary process. It may eventually prove necessary or useful to break it down further. The input for ACT includes the observation action concept and the differentiated object on which the action is to be performed. The output is the resulting input to the individual. Analysis of the input is carried out by other processes.

SELECT

This is a primary process which sorts relevant information from irrelevant. In particular, it filters out almost all information except for that for the variable (or variables) judged relevant to the task at hand. Thus, the input is undifferentiated input and the variable concept. The output is information on the relevant variable about the perceived object. Actually, the process is not simply a next step following complete execution of ACT. Rather, along with

ACT it forms an active system with a feedback capability which allows modification of the detailed functioning of ACT until the appropriate input has been made available. This represents a monitoring function of SELECT. Such feedback mechanisms are probably involved in many primary processes. The large number makes it cumbersome to make them all explicit in the task routine. This aspect of the primary process is probably important to keep in mind, however.

ENCODE

This primary process analyzes in detail information which has been attended to, e.g., as a result of SELECT. The general nature of the information has already been determined (note the nature of ACT and SELECT) and it remains for ENCODE to make a determination about this specific case. For example, ENCODE might be preset to analyze texture information. ACT and SELECT have made such information available. ENCODE determines whether or not the texture information is novel and, if not, categorizes it in some manner based on previously experienced texture information. If the information is novel, a new category is created. Thus, ENCODE involves long-term memory. In terms of an associative network, the analysis of texture information activates a node representing a texture value concept or else forms a new node paralleling other texture value nodes. The input for ENCODE is selected non-verbal sensory information. The output is a value concept (the activation of a node). Undoubtedly, some additional contextual information about the experience will enter short-term memory. Some may also enter long-term memory.

OTHER PRIMARY PROCESSES

COMPARE

This primary process determines the comparability of two encoded units of information, e.g., encodings of texture information for two objects. COMPARE essentially monitors the node or nodes activated as a result of the encodings. If the same node is activated on both occasions, a judgment of comparability is made. If different nodes are activated, a judgment of non-comparability is made. The output of COMPARE can itself be viewed as the activation of a node in a network. This network includes nodes corresponding to the concepts "same" and "different" (and perhaps others). The activation of one of these nodes makes immediately available certain operational alternatives including verbal output. The particular alternative to be executed, if any, is determined by some controlling mechanism which represents the strategy being employed by the individual.

PLACE

This primary process involves a spatial placement of an element to indicate its membership in a set. The criterion for placement is unspecified in the process itself although it will usually be retained in short-term memory from earlier steps. The input to the set is an element currently attended to and an affirmative result from the application of the criterion for set membership. The output is the element in its new spatial location. A variety of contextual information placed in short-term memory usually enables the individual to recognize the subset previously set aside by PLACE.

DISCARD

This primary process is closely related to PLACE since it involves spatial placement of an element to indicate nonmembership in a set defined by a criterion from a previous step. However, DISCARD is not simply PLACE using the inverse criterion since DISCARD implies that the element is of no further interest, at least temporarily. Previously discarded elements can subsequently be reconsidered for further processing, however: DISCARD can be used to form more than one discard set during the performance of a single task. Furthermore, the permanency of the discard may differ between sets, e.g., one set may be discarded for the time being while another is permanently discarded.

ORDER

This is a primary process which attends to and assesses the magnitudes of two differing encoded units of information. ORDER sequentially evaluates the two magnitudes and then hierarchically orders them from lesser to greater. This primary process then basically monitors the nodes activated as a result of the encodings. The COMPARE secondary process usually precedes and determines whether or not different nodes were activated during encoding. If this results in a judgment of non-comparability, it is the function of ORDER to evaluate the two nodes successively and to seriate them appropriately. The output of ORDER can itself be viewed as an ordinal concept, i.e., the activation of a node in a network. This network includes nodes corresponding to the concepts of "more" and "less" (and perhaps others). The activation of one of these nodes makes immediately available certain operational alternatives including verbal output and appropriate serial positioning of the elements. The particular alternative to be executed, if any, is determined by some controlling mechanism which represents the strategy being employed by the individual.

POSITION

This is a primary process which functions much like PLACE. It allows representation of information about relations between elements to be coded temporarily by spatial position. Whereas PLACE utilizes only spatial proximity POSITION uses linear sequence. Thus, POSITION requires discrimination of the "greater than" and "less than" directions in a linear array and one or two previously ordered elements relative to which the new element will be located. The process must be capable of spreading out the linear array to make room for a new element if necessary. Also, it must be able to place an element beside an ordered one on a line perpendicular to the array to indicate sharing the same position. The input is an element, a set of ordered elements with one or two distinguished as a reference, and an ordinal concept which relates the new and reference elements. The output is a set of elements with the original order preserved and the new element properly positioned with respect to the reference element(s).

REPORT

This is the process by which verbal responses are made. The input is a concept. The output is a verbal label for the concept embedded in an appropriate linguistic context (not necessarily a complete or correct sentence).

PRESENT

This is a primary process which can be used to indicate an element or set of elements as a task output. This may be used to communicate nonverbally the result of a task which requires element selection or formation of a set of elements. The process involves a directing gesture and some device for delimiting the referent of the gesture. This could be a further gesture or a spatial separation of the element or elements.

DESIGNATE

This process assigns a specific role to an element or set of elements for use in further processing. For example, one element may be assigned the role of model for formation of a subset. Subsequent processing steps treat the element in a manner appropriate to the assigned role.

This process can be conceived as a temporary association of identifying features of the element with a conceptual node representing the specific role assigned. However, the role concept is not an integral part of a conceptual network including the specific variable, values, observation action, etc. Rather, it is part of a network associated with the strategy. The DESIGNATE process is somewhat similar to the RETRIEVE process in that part of the input comes, not from the previous processing steps, but from some directing mechanism or representation of the strategy. In this case, the perceptually differentiated element is the output of preceding processing steps but the specific role to be assigned is not. The nature of the controlling mechanisms and the representation of the strategy in memory have not been further elaborated.

In the context of the processing routine, the input is the perceptually differentiated element, and the output is that element assigned to the specified role. This description of the output is vague, but the effect of this processing step is reflected only in the way the element is employed in future steps.

SEARCH

This is a loosely defined process which involves construction and execution of an action program for finding some object in this environment. It takes as input a concept or activated node representing the searched-for object. The process utilizes any available information from memory concerning the probable location of the object, routes to it, etc., as well as any available visual scanning and other search strategies. The output of the process is the object which is then available to the individual for further processing.

SECONDARY AND TERTIARY PROCESSES

INFORM (variable concept → variable name or value name)

INFORM is a secondary process which produces a verbal report identifying a specific variable (see Figure 3). The input is usually a variable concept or value concept. The output is a variable name or, if the variable name cannot be retrieved, values describing one or more elements on the variable.

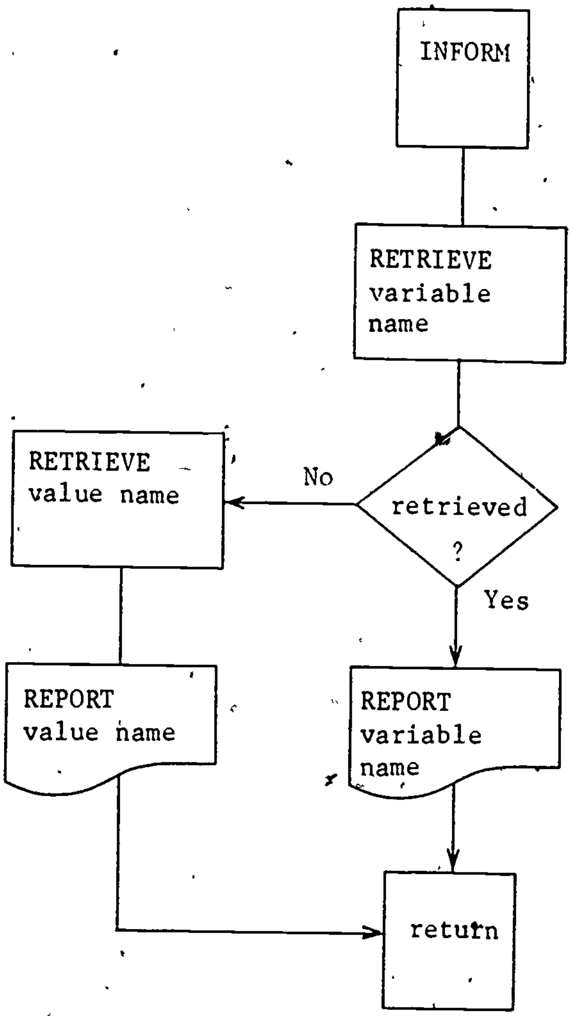


Figure 3. The INFORM secondary process. Input: A variable concept. Output: A variable name or value names.

COMPARISON (variable concept, Element A, Element B → comparative concept)

This is a secondary process which takes as input a variable concept (i.e., the node activated by decoding of variable name or an appropriate retrieval process) and an ordered pair of elements. It compares the elements on the given variable and outputs a comparative concept applicable to the ordered pair of elements. Thus, the COMPARISON process does not produce a verbal report although it makes such a report immediately possible. Alternative steps might be carried out next instead. The identities of the elements and the comparison variable are maintained. Figure 4 indicates a parallel execution of processing steps. This indicates the desirability of near simultaneous observation of the two elements. "Parallel processing" in the technical psychological sense is not implied. Furthermore, feedback from the selecting and encoding steps to the ACT step undoubtedly occurs creating an active subsystem. Such feedback systems are very common, but to avoid excessive complexity, are not always diagrammed.

SERIATION (variable concept, Element A, Element B → ordinal concept)

This tertiary process (Figure 5) uses as input a variable concept and a pair of elements. It initially processes the elements utilizing the COMPARISON process. If the elements are of the "same" magnitude on the variable observed, SERIATION outputs a comparative concept applicable to the elements. If the elements are not of the same magnitudes, SERIATION assesses the relative magnitudes of the elements using the ORDER process. This process outputs an ordinal

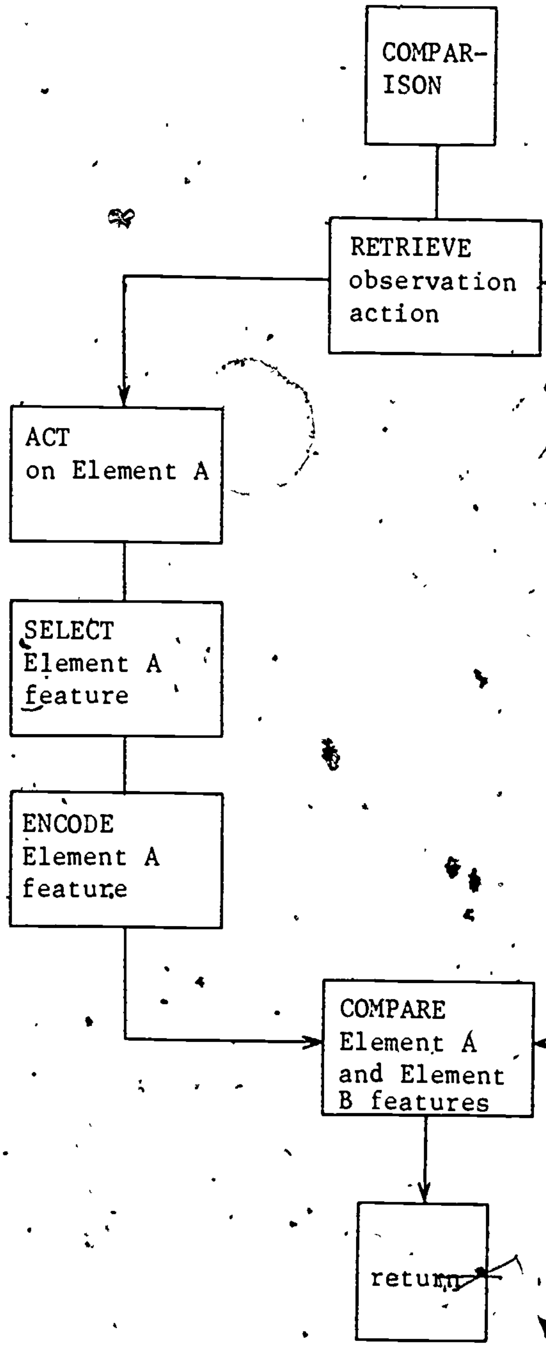


Figure 4. The COMPARISON secondary process. Input: A variable concept, Element A, and Element B. Output: A comparative concept relating Element A, and Element B on the input variable.

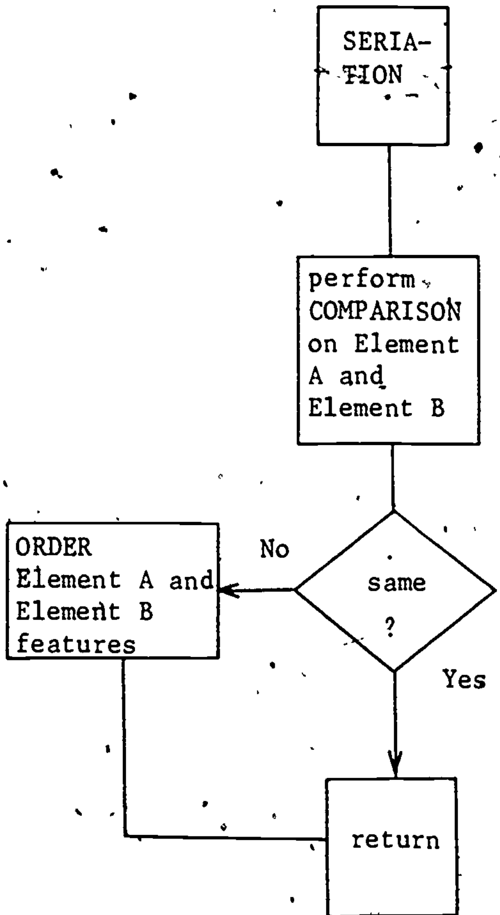


Figure 5. The SERIATION secondary process. Input: A variable concept, Element A, and Element B. Output: An ordinal concept relating Element A, and Element B on the input variable.

concept, "greater than" or "less than". The identities of the elements must be maintained and coordinated with the ordinal concept. The SERIATION process does not produce a verbal report although it makes such a report immediately possible. Motor manipulation and sequential ordering of the elements themselves are also possible. The identity of the seriation variable is maintained.

MATCH (set of elements, model element, variable concept → elements comparable to the model on the variable)

This tertiary process (Figure 6) involves multiple applications of the COMPARISON process. The input is a set of elements, a perceptually differentiated model element, and a variable concept. Pairwise comparisons are made with those elements found comparable to the model being grouped spatially. The recycling terminates when all elements have been used. The output is a subset of elements, each comparable to the model on the given variable. The identities of the model and the variable are maintained.

MATCH 1 (Set of elements, model element, variable concept → an element comparable to the model on the variable)

This tertiary process is very similar to MATCH. However, it terminates when one element is identified as being comparable to the model (see Figure 7). Thus, the output is a single element similar to the model on the input variable.

NONMATCH (variable concept, element, set of members → placed/discarded element depending on whether or not it differs from all of the members on the input variable)

This tertiary process determines whether or not an element differs from each member of a set on a particular variable. The process chooses

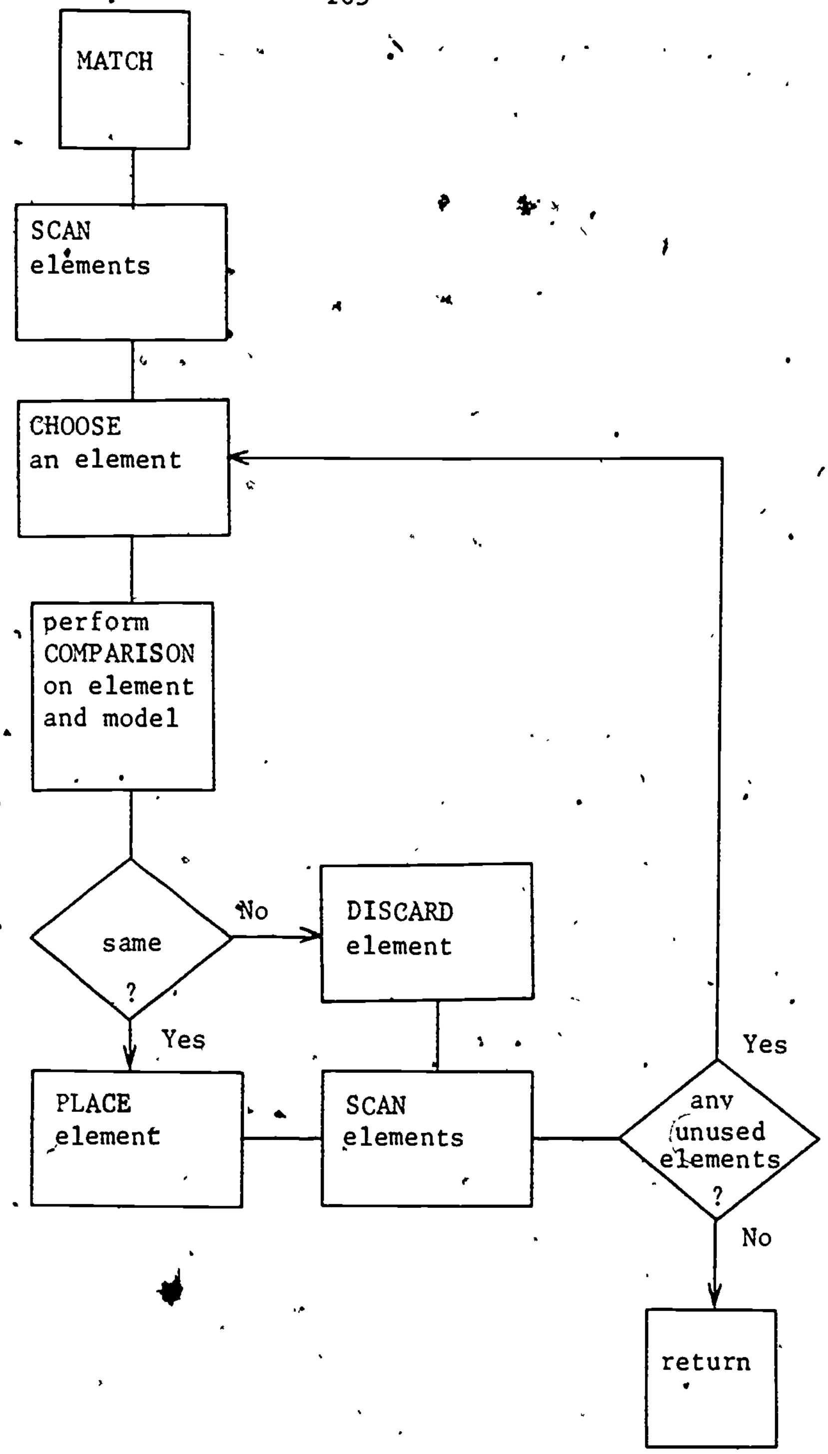


Figure 6. The MATCH tertiary process. Input: A variable concept, a set of elements, and a model. Output: A subset of elements similar to the model on the input variable.

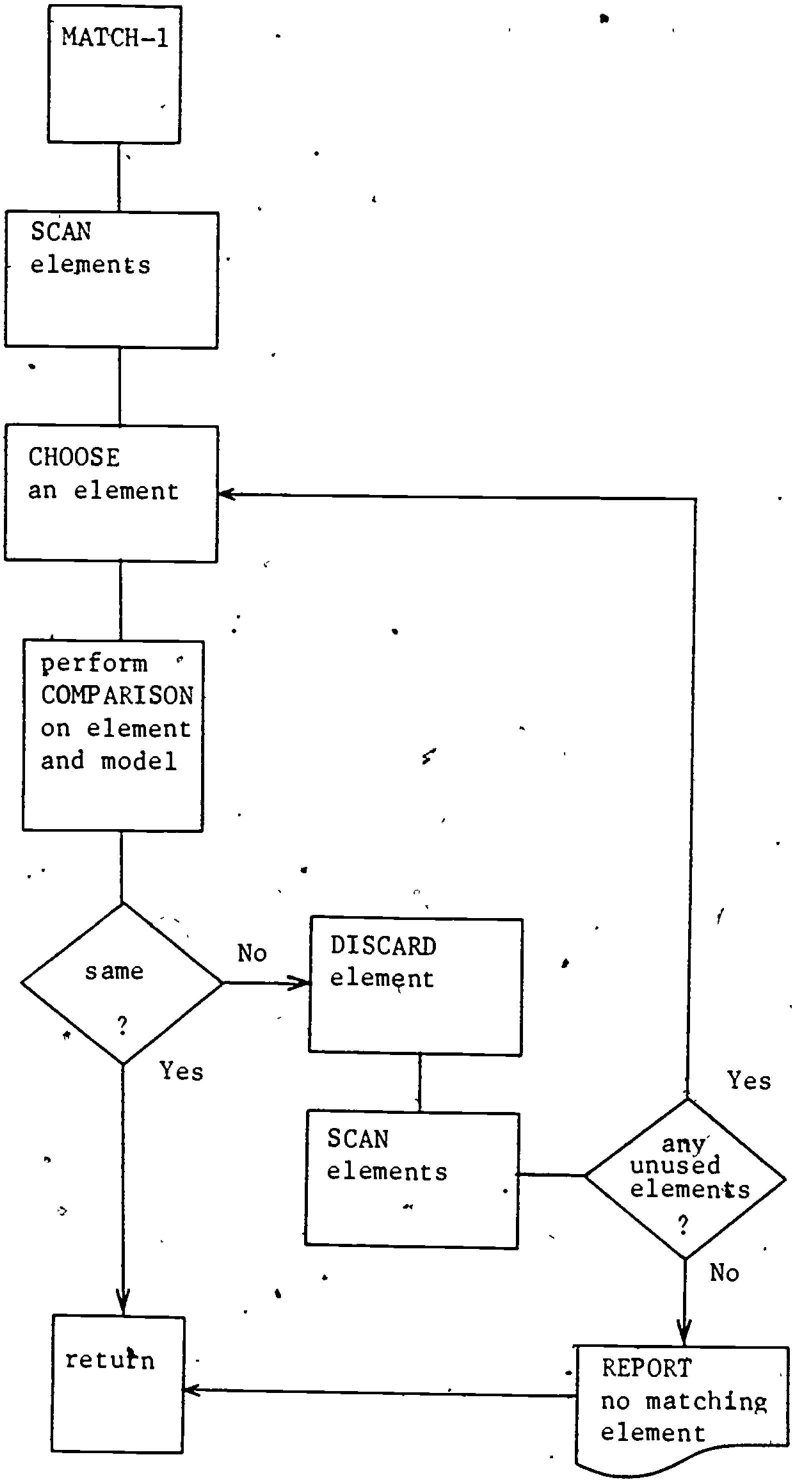


Figure 7. The MATCH-1 tertiary process. Input: A variable concept, a set of elements and a model. Output: An element similar to the model on the input variable.

standards one at a time and makes pairwise comparisons with the element using the COMPARISON process, (see Figure 8). If the element is the same as any member, it is discarded. If it differs from all of them, it is placed with them and is itself designated a member.

PROCESSING ROUTINES

In this section, processing routines in the form of flowcharts are described which represent solution alternatives for a set of tasks based on the variable-value analytic network (Smith, 1972). The fundamental processes involved are identified by name in the flowcharts. Rectangular boxes represent primary processes while square boxes represent secondary or tertiary processes.

PROCESSING ROUTINES FOR DESCRIPTION TASKS

Processing routines are presented for three description tasks. The tasks (Table 1) require pairing an element with one or more descriptive values utilizing an observation procedure. The strategies devised for these tasks (Figure 9-11) involve matching an element to one of a set of standard elements for a variable. Pairwise comparisons are utilized in the matching secondary processes MATCH and MATCH-1. The standard may be labeled or not. If unlabeled, the individual must be able to retrieve the appropriate value label for a standard from long-term memory. Although this approach appears cumbersome and somewhat superfluous for some familiar values such as the primary colors, it provides a means for dealing with new, unfamiliar values.

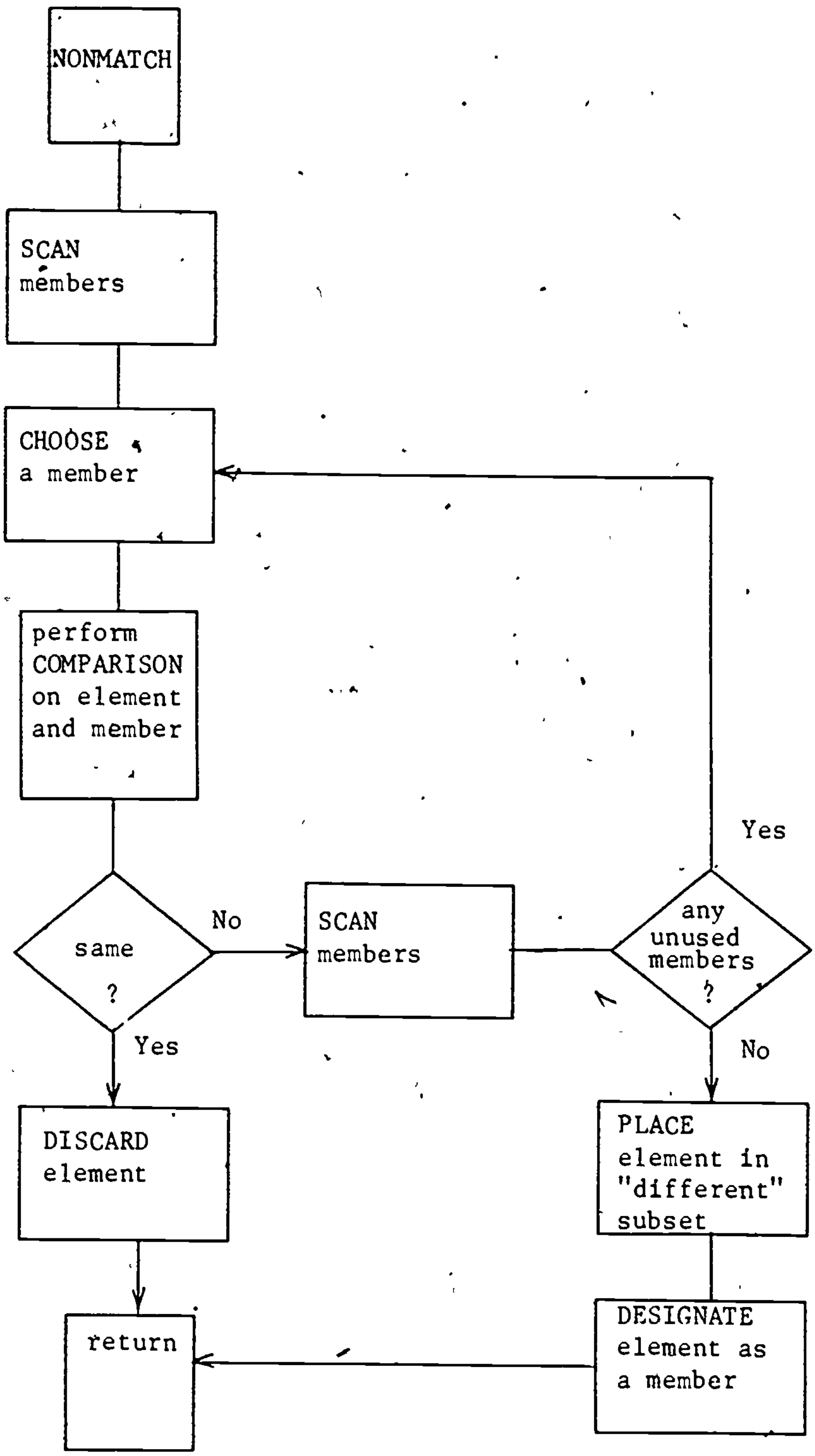


Figure 8. The NONMATCH tertiary process. Input: A variable concept, an element, and a set of members. Output: A placed/discarded element, depending on whether or not the element differs from all the members on the input variable.

TABLE 1

SIMPLE DESCRIPTION TASKS

Task Name	Given Input	Required Output	Sample Item
Element Identification	a set of <u>elements</u> a <u>value</u> for a variable	an <u>observation/measurement procedure</u> for the variable an <u>element</u> described by the given value	Given samples of salt, sugar, flour, sand, and chalk. "Which substance is soluble in water?"
Directed Description	an <u>element</u> a <u>variable name</u>	an <u>observation/measurement procedure</u> for the named variable a <u>value</u> for the named variable which describes the given element	Given a mineral specimen. "Determine and report the hardness of this rock."
Nondirected Description	an <u>element</u>	an <u>observation/measurement procedure</u> for a variable a <u>value</u> describing the given element on that variable (multiple cycles may be required)	Given a leaf specimen. "Describe this leaf as completely as you can."

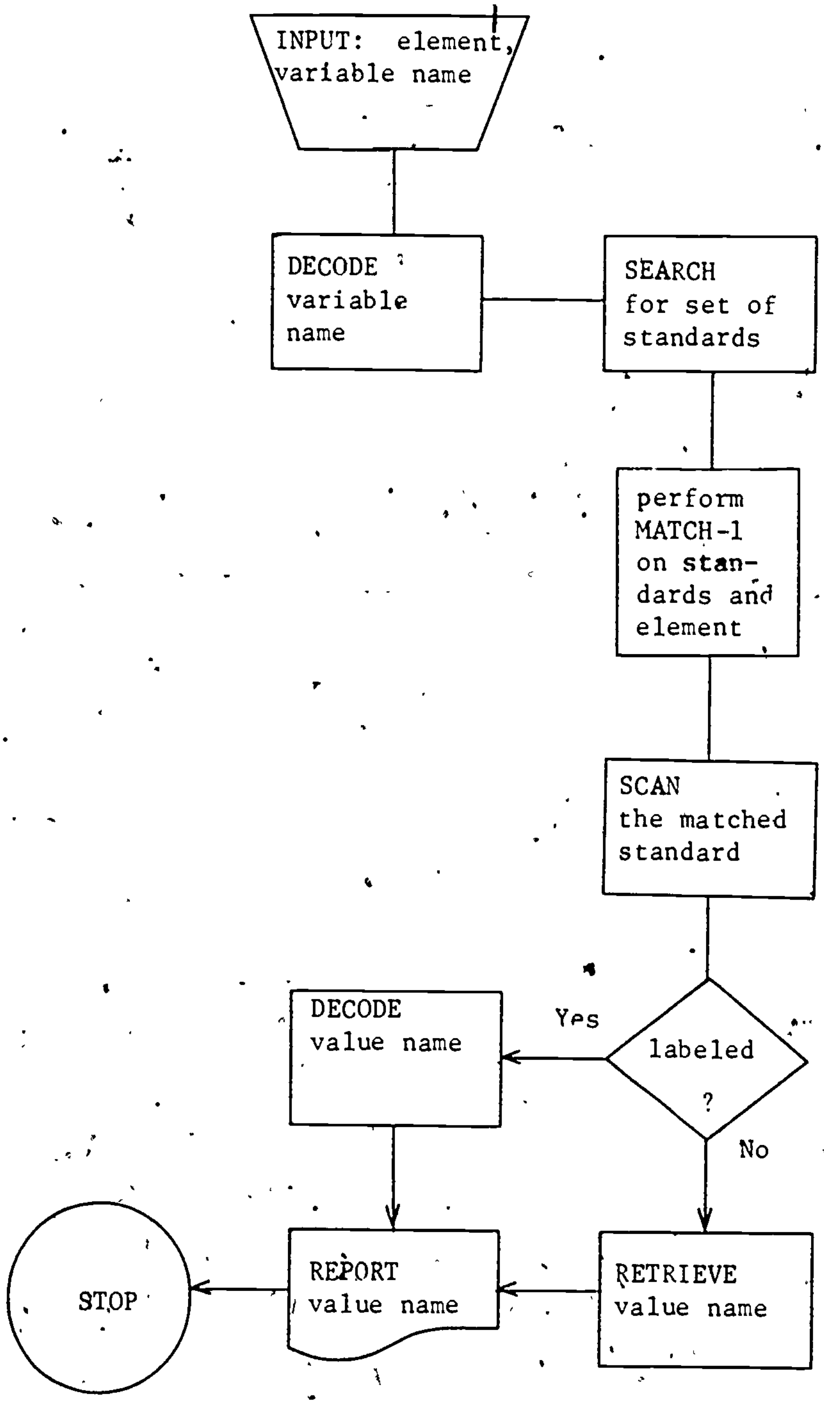


Figure 9. Processing routine for the directed description task (employing standards).

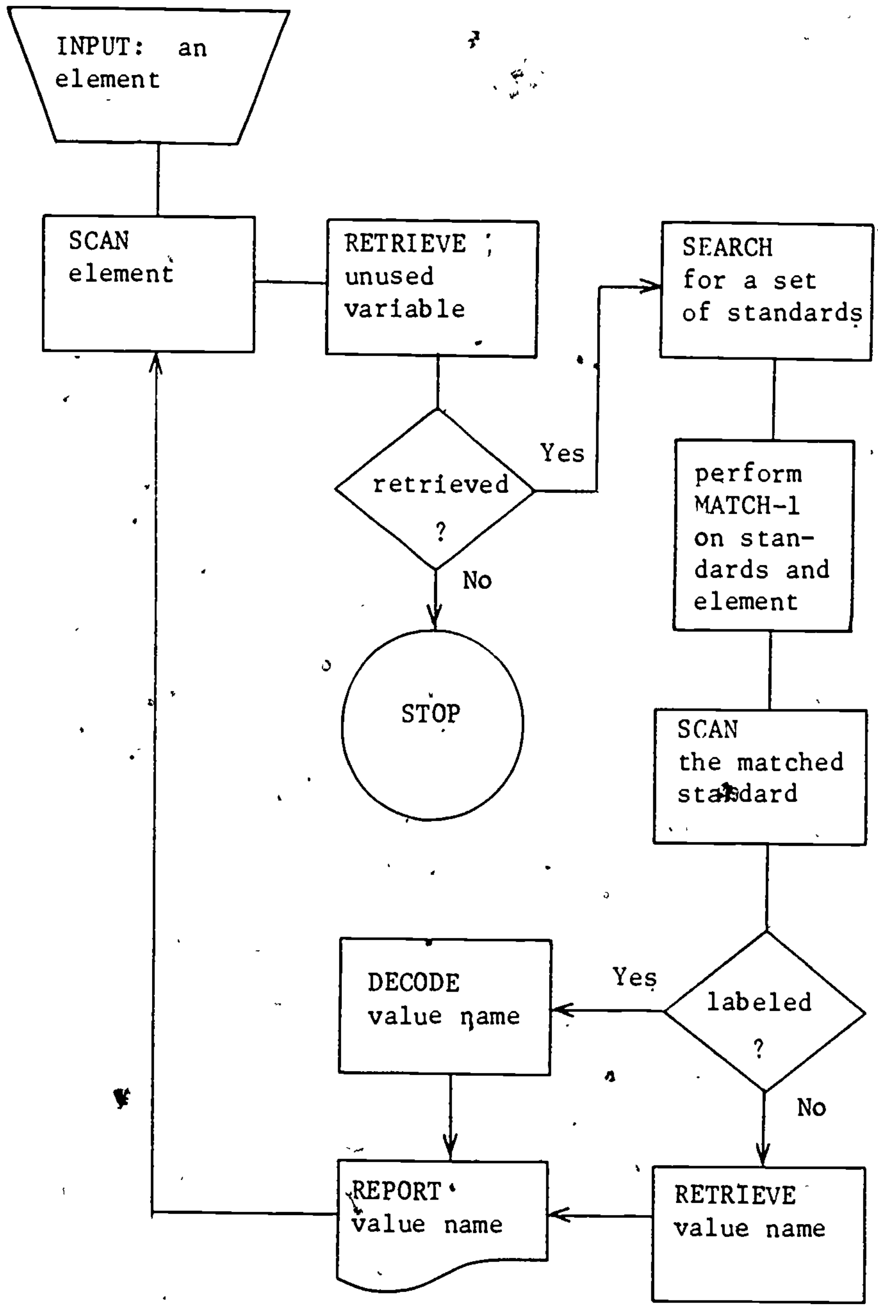


Figure 10. Processing routine for the nondirected description task (employing standards).

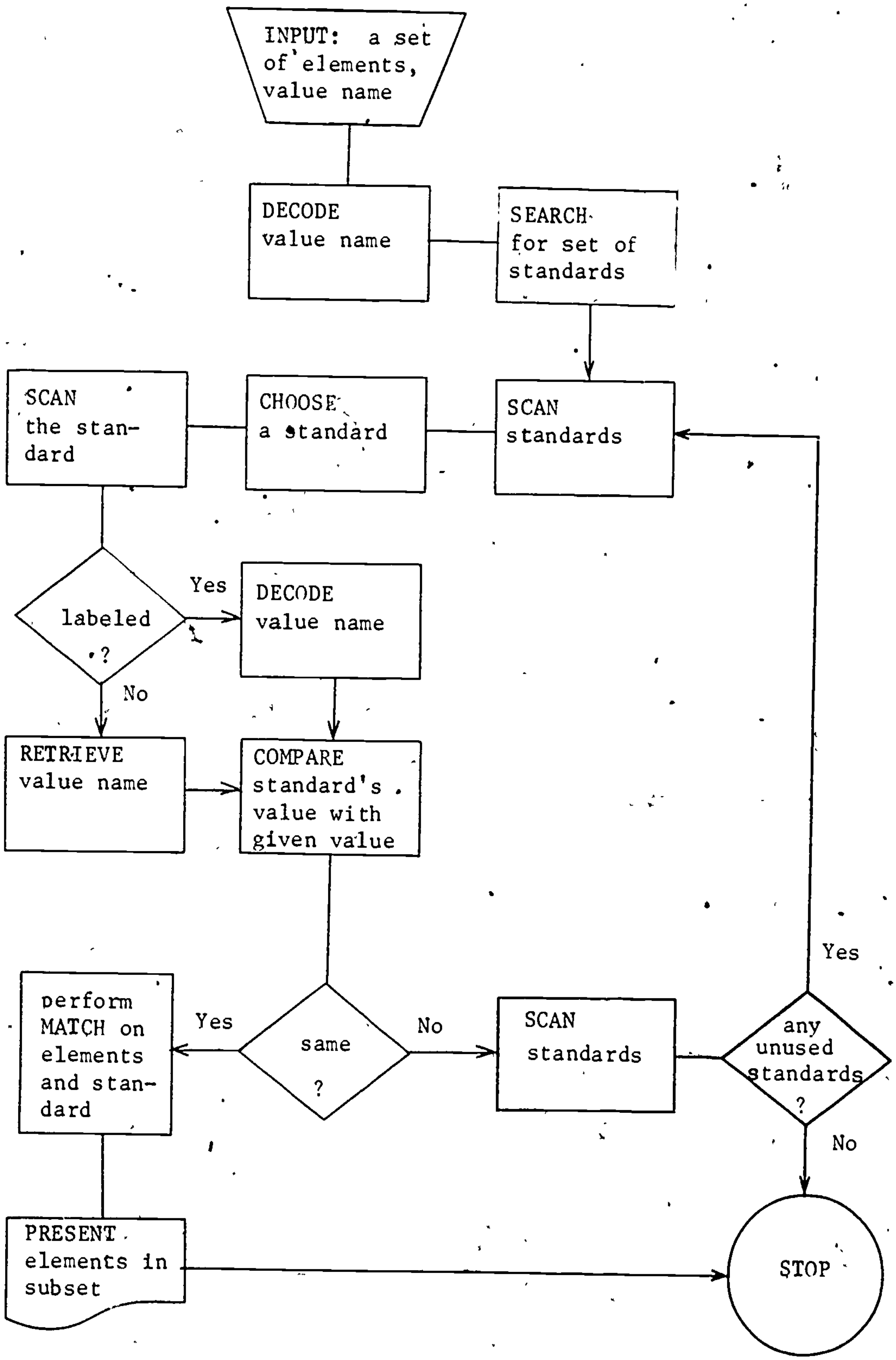


Figure 11. Processing routine for the element selection task (employing standards).

More importantly, it provides a basis for development of measurement strategies, and the use of unit standards of measurement in particular. It can be short circuited when the individual attains sufficient familiarity with the relevant features and labels.

PROCESSING ROUTINES FOR COMPARISON TASKS

The comparison tasks (Table 2) involve a single set or subset of elements exhibiting a particular comparative relation (similarity or difference) on a variable (e.g., a set of teeth all having similar forms). All of the processing routines for these tasks (Figures 12-17) involve using spatial grouping to indicate subset membership, designating the first element chosen to serve as a subset model, and scanning for unused elements as a basis for determining whether or not to continue in a processing loop. They utilize pairwise comparison of an element and a model with the placement of the element in the subset contingent on the result. The routines for the subset formation and comparison variable identification tasks using the difference criterion (Figures 15 and 17) have one level of recycling embedded in another. The inner loop compares a new element with each member already in the subset. The outer loop obtains new elements one at a time until none remain.

PROCESSING ROUTINES FOR SORTING TASKS

The sorting tasks (Table 3) involve exhaustive placement of elements into subsets based on similarity on a variable (e.g., leaves sorted according to the type of edge they possess). The strategy employed in the routines of these tasks (Figures 18-20) involves

TABLE 2

COMPARATIVE TASKS

Task Name	Given Input	Required Output	Sample Item
Comparison Variable Identification	a set of elements a comparative	the name of a variable for which the given comparative value characterizes the relation between the given elements (multiple cycles may be required)	Given a bean plant, a corn plant and a cactus. "In what ways are these plants the same?" (e.g., color, means of attachment)
Directed Comparison	a set of elements a variable name	the comparative value characterizing the relation between the given elements on the named variable	Given a bean leaf and a corn leaf. "compare the shapes of these leaves." (e.g., different)
Nondirected Comparison	a set of elements	a variable name the comparative value characterizing the relation between the given elements on the named variable (multiple cycles may be required)	Given a mouse, a frog, and a lizard. "Compare these animals." (e.g., same number of legs, different body covering)
Subset Formation	a set of elements a variable name a comparative value	a subset of elements such that the relation between them on the named variable is characterized by the given comparative value	Given specimens of teeth from a cow, a man, a dog, and a rat. "Pick out some teeth which have the same shape." (e.g., the double molars)

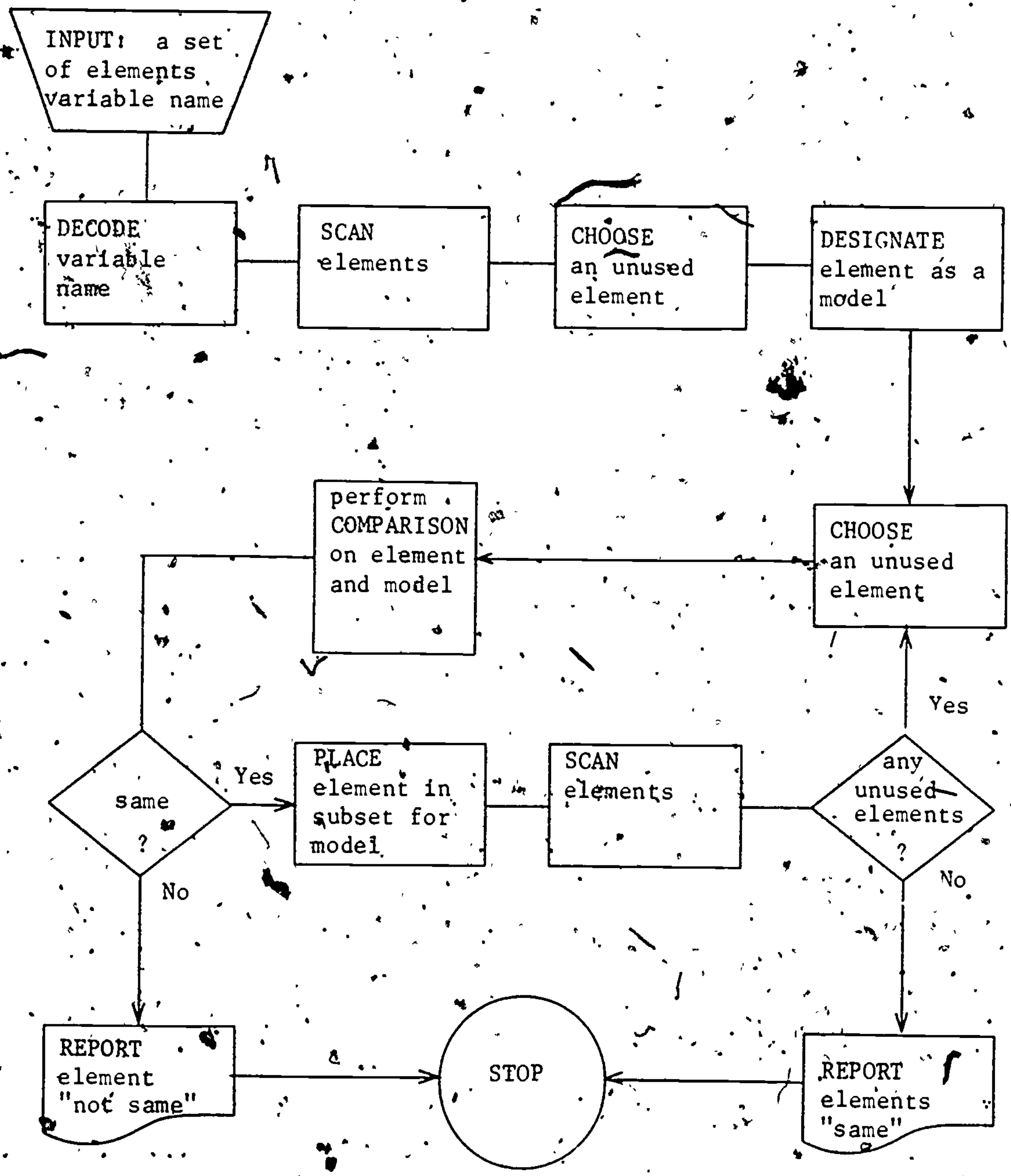


Figure 12. Processing routine for the directed comparison task.

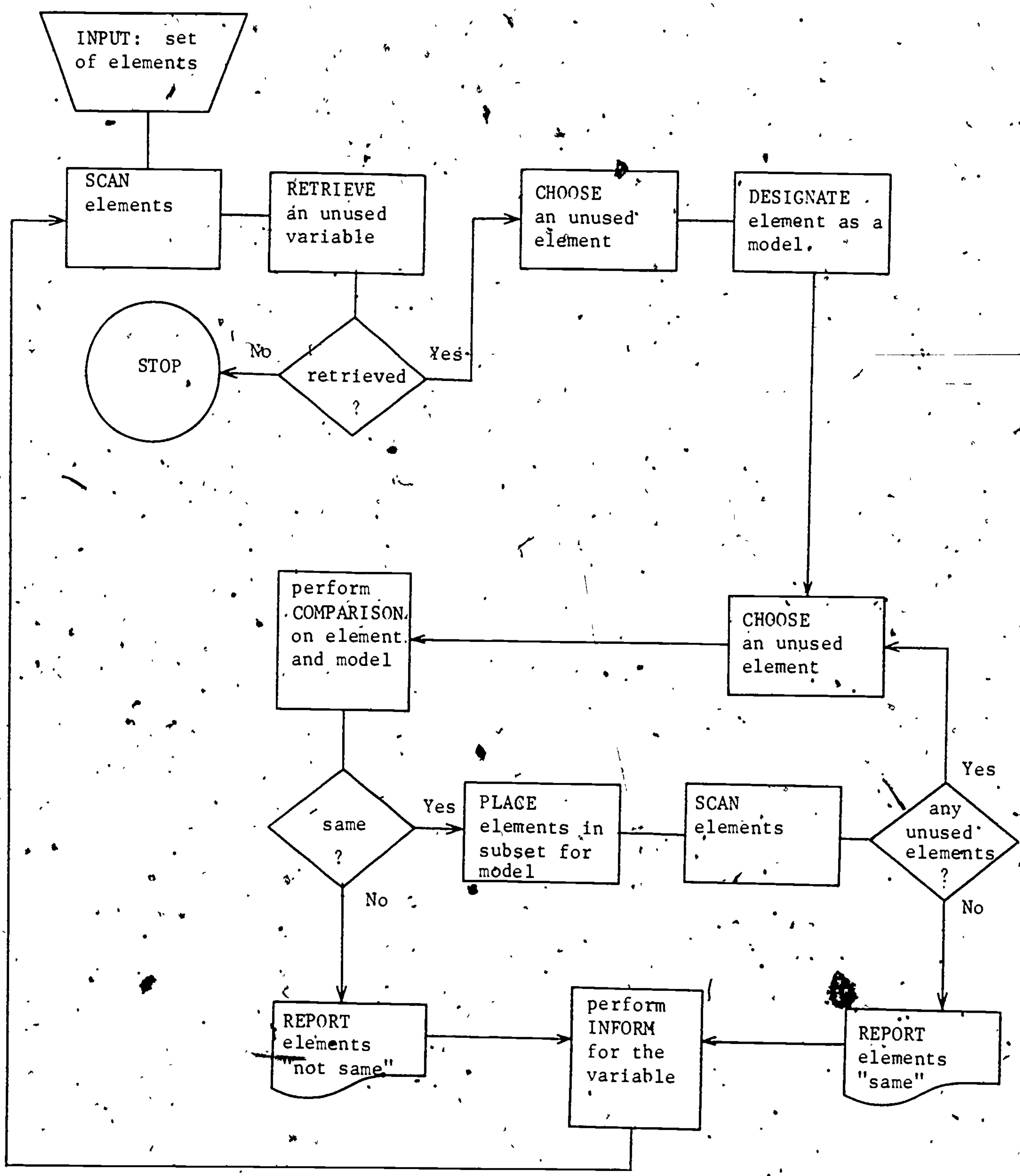


Figure 13. Processing routine for the nondirected comparison task.

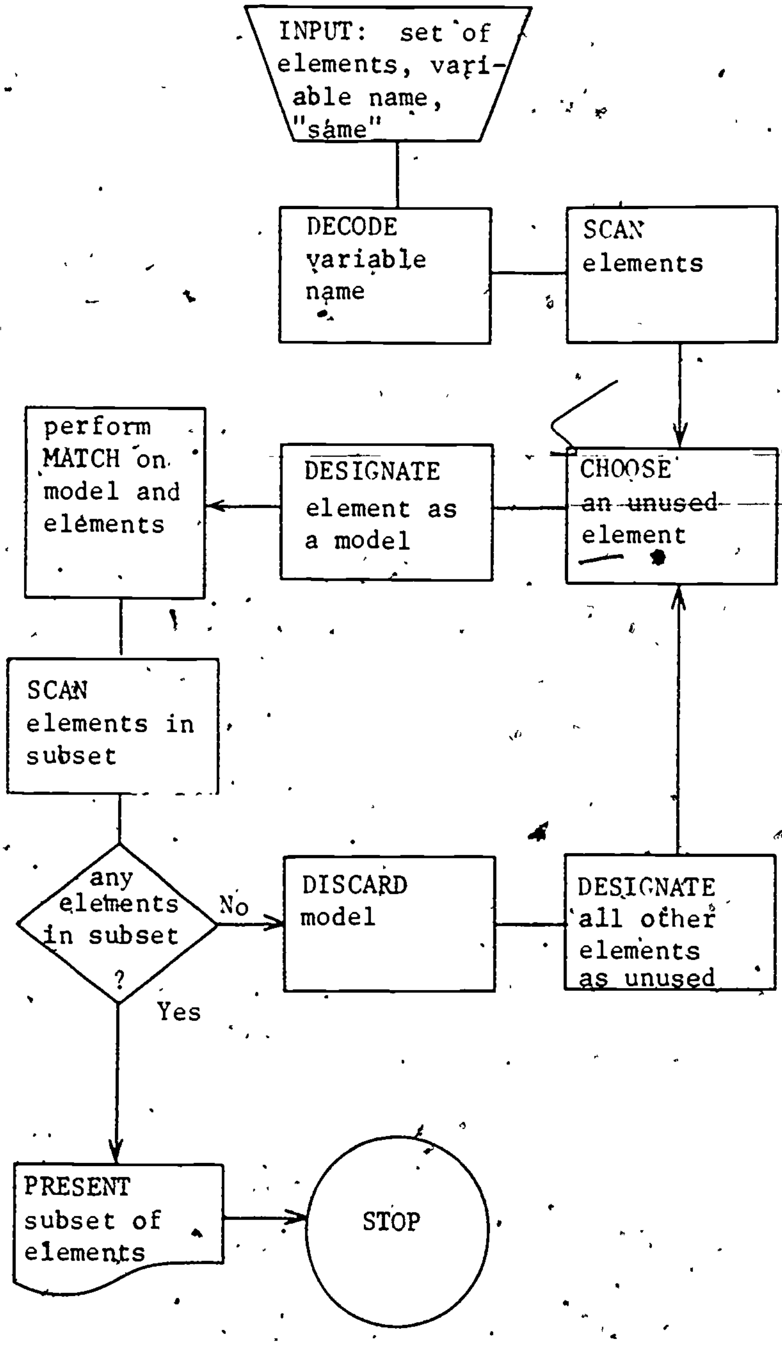


Figure 14. Processing routine for the subset formation task with the similarity criterion.

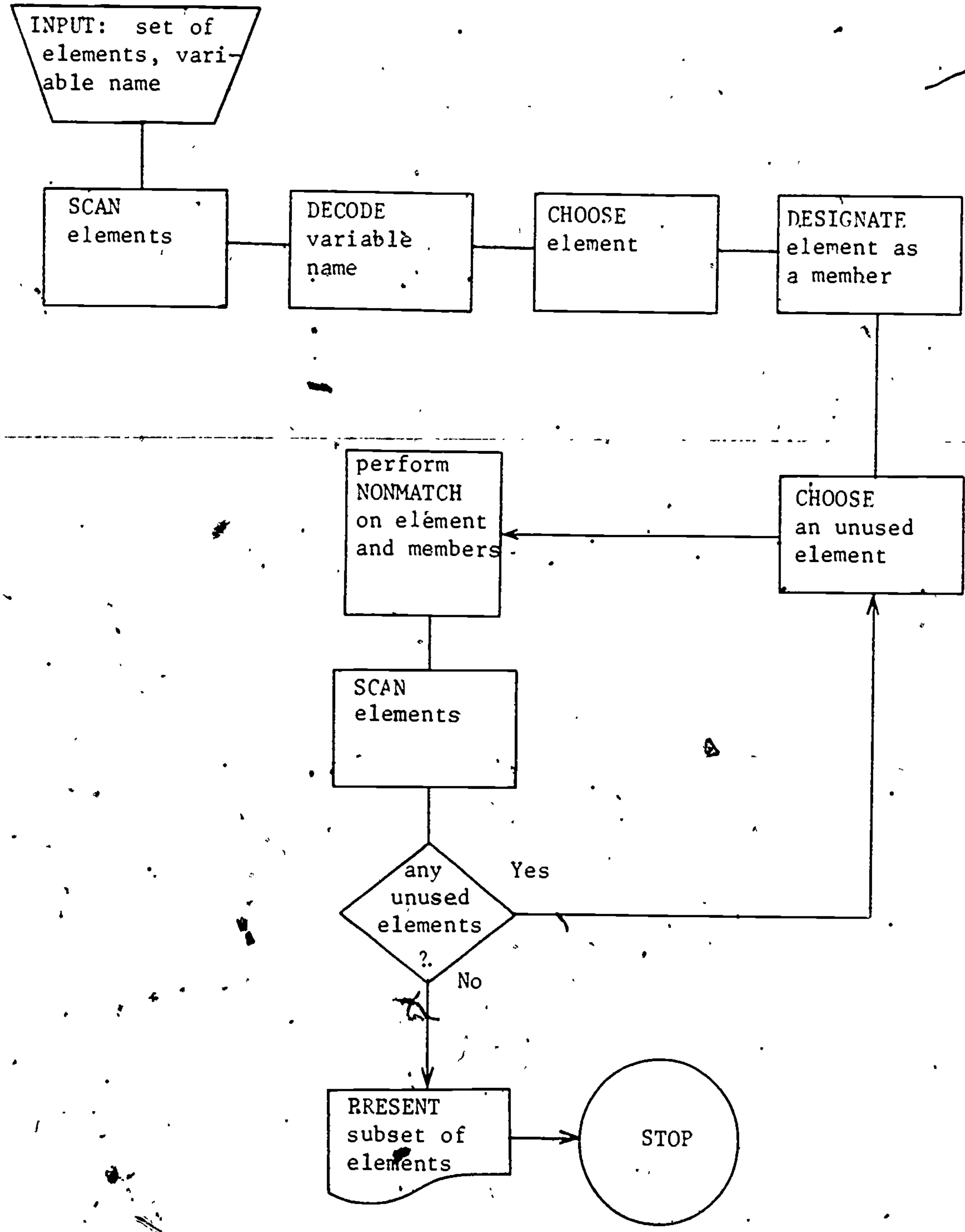


Figure 15. Processing routine for the subset formation task with the difference criterion.

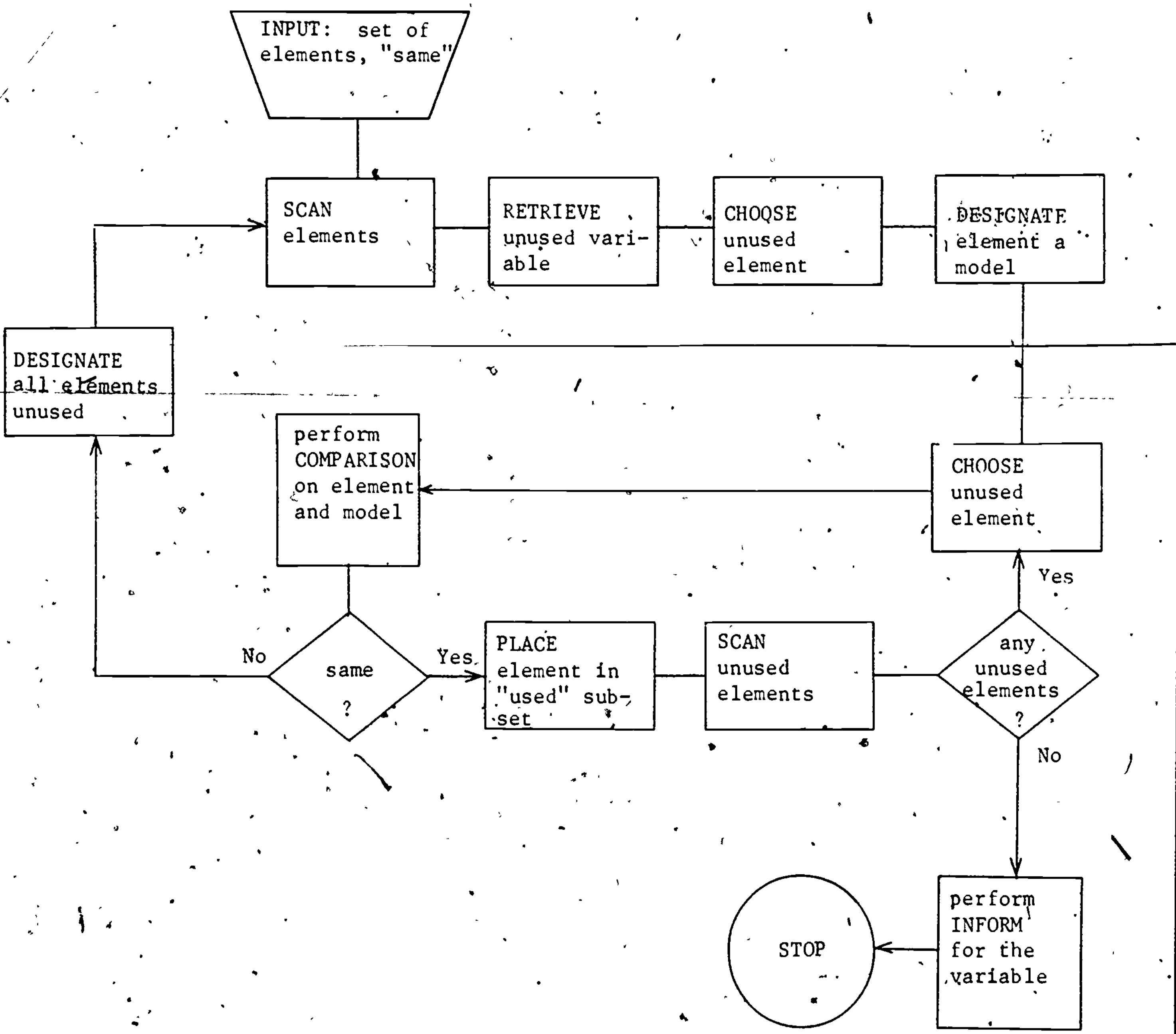


Figure 16. Processing routine for the similarity variable identification task.

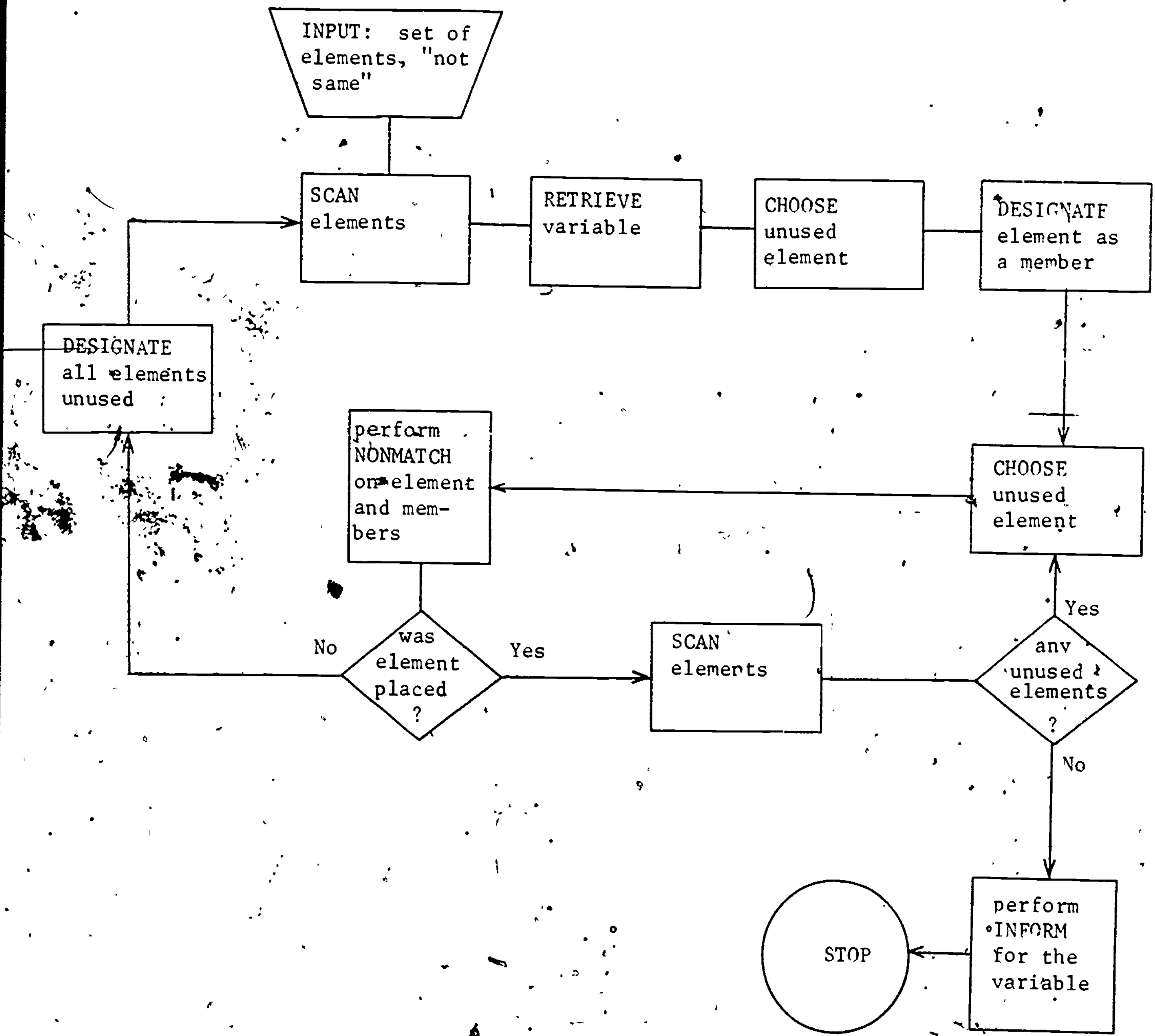


Figure 17. Processing routine for the difference variable identification task.

TABLE 3

SORTING TASKS

Task Name	Given Input	Required Output*	Sample Items
Nondirected Sorting	a set of elements	the set sorted into subsets on a specific variable the name of the variable	Given samples of liquids differing in color, viscosity and opacity. "Sort these substances into groups on one variable."
Sorting Variable Identification	a set of elements sorted into subsets on a specific variable	the name of the variable on which the elements are sorted	Given drawings of irregular polygons differing in area and number of sides, sorted by number of sides. "How have these figures been sorted?"
Directed Sorting	a set of elements a variable name	the set sorted into subsets on the named variable	Given a set of small common objects and access (but not direction) to a container and water. "Sort these objects by their buoyancy."

*An observation/measurement procedure is required output for each task.

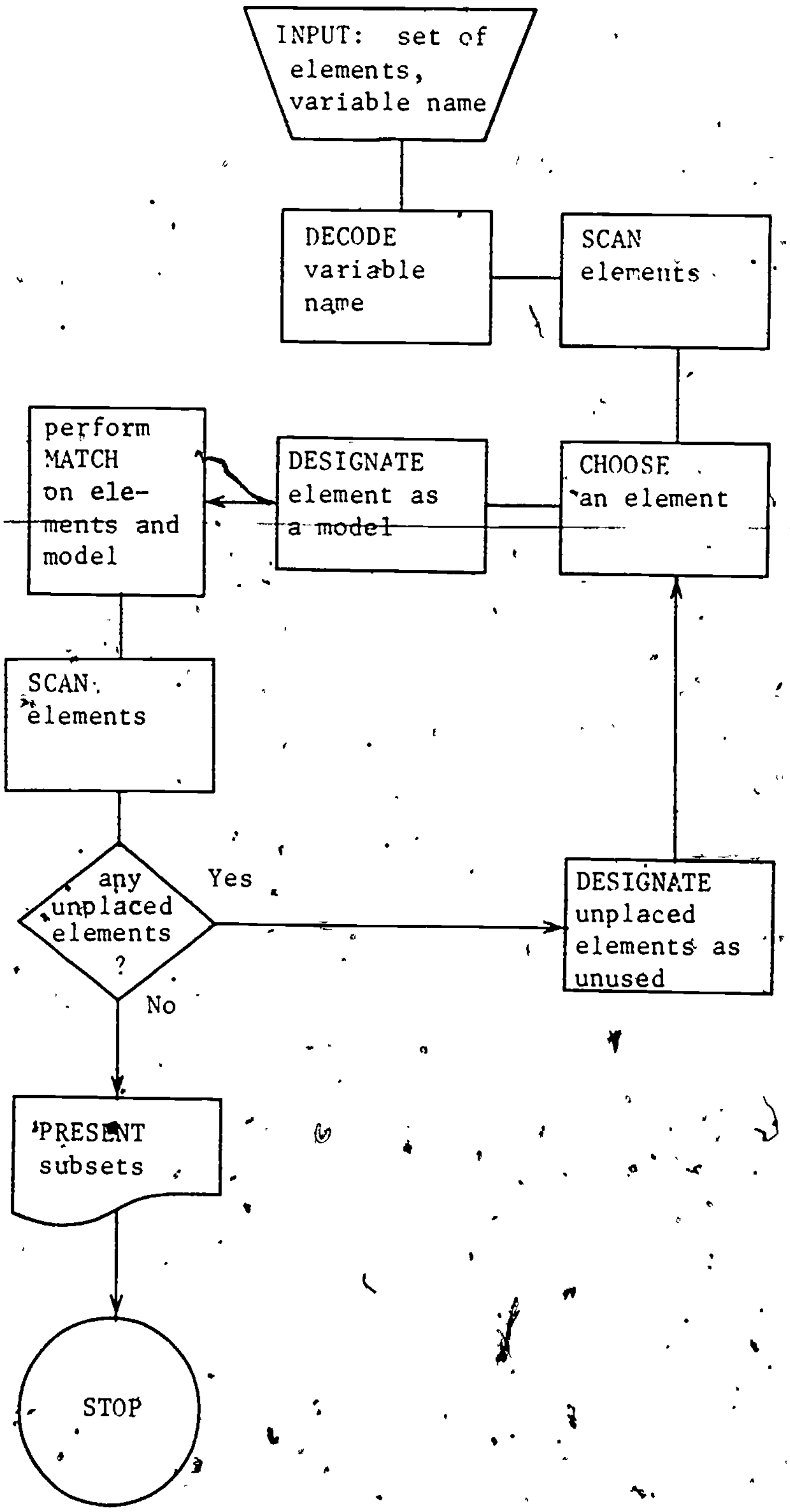


Figure 18. Processing routine for the directed sorting task.

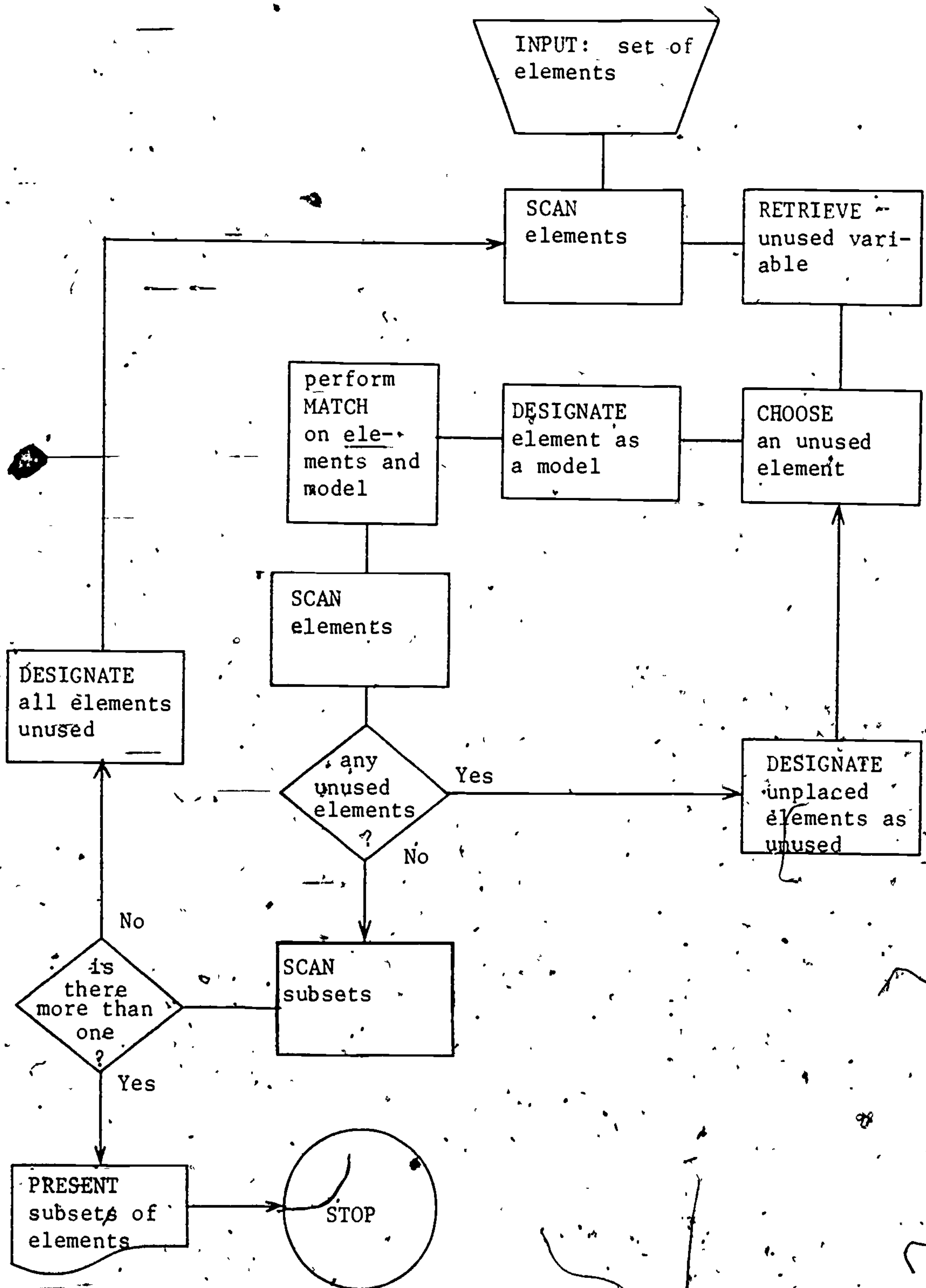


Figure 19. Processing routine for the nondirected sorting task.

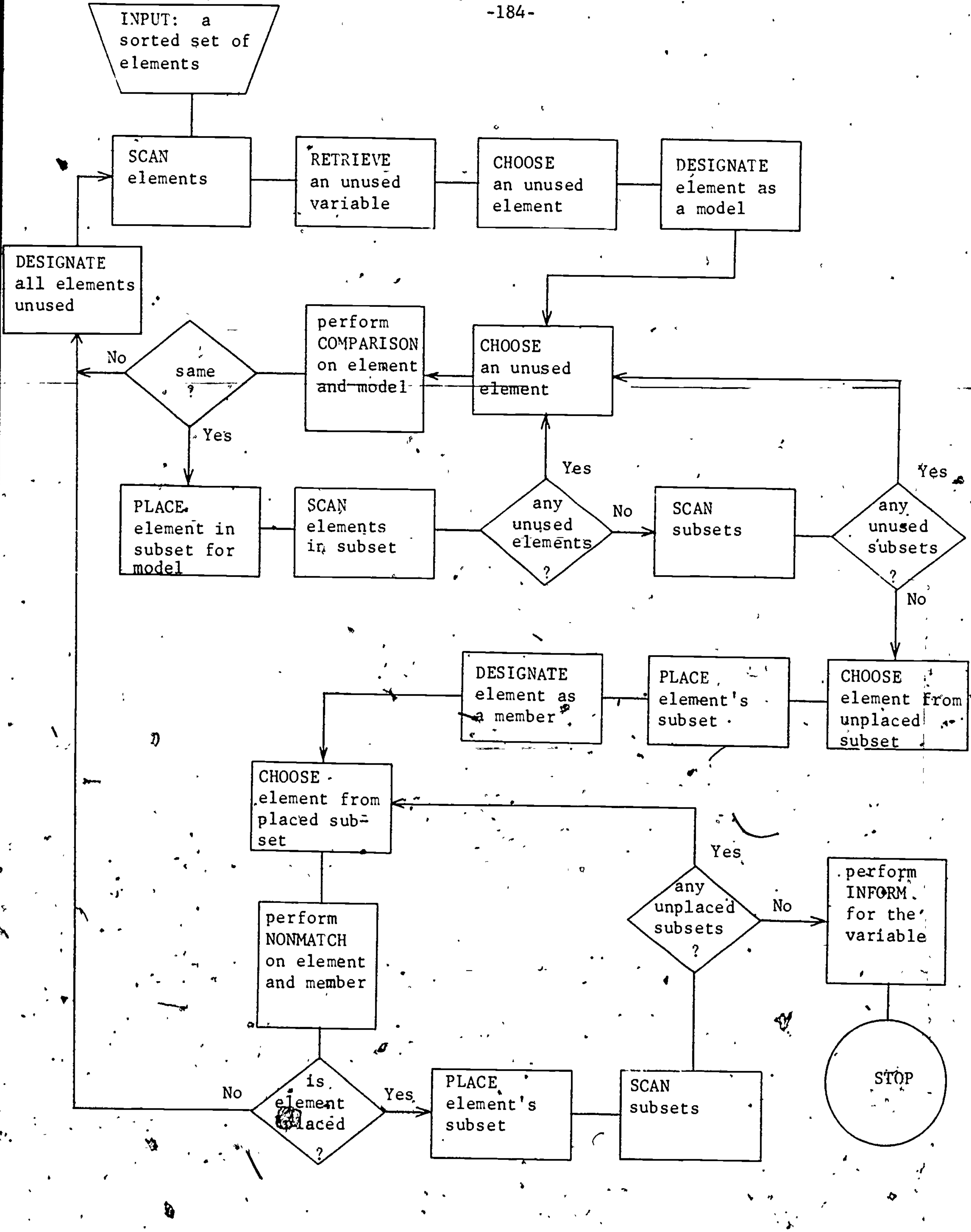


Figure 20. Processing routine for the sorting variable identification task.

choosing an element to use as a model and then identifying all other elements similar to it on the sorting variable, temporarily discarding all others. This is repeated with the remaining elements until all are sorted. This is essentially a repetitive use of the strategy employed for the comparison tasks with the similarity criterion. As with the comparison task routines~~, spatial grouping is used to indicate subset membership, and individual elements are specified as subset~~ models. The repetitive use of the subset formation strategy requires two levels of recycling. One depends on there being unused elements during the formation of a subset, while the other depends on there being unplaced elements remaining after completion of a subset.

The sorting variable identification routine (Figure 20) has two parts. The first determines whether or not all elements in each subset are similar on the variable under consideration and involves the strategy just described. The second part determines whether or not all the subsets differ from each other on the variables. The strategy employed here involves choosing an element from one subset and comparing it to one element chosen from each of ten other subsets. If it differs from all of them, its subset is set aside and an element from a second subset is compared to one from each of the remaining subsets. This is repeated until only one subset remains or until similar subsets are detected. The detection of similar subsets indicates that an inappropriate variable was chosen and the entire routine is repeated with another variable.

PROCESSING ROUTINES FOR SERIATION TASKS

The seriation tasks (Table 4) involve sets of elements ordered along a specific variable. The three tasks parallel the sorting tasks. That is, there are directed and nondirected seriation tasks, and a seriation variable identification task. The routine for the directed seriation task was presented and briefly described earlier (Figure 2). The strategies for this and the other seriation tasks (Figures 21 and 22) utilize spatial representation of the order on the seriation variable. The same strategy is employed in the directed and nondirected seriation tasks. It involves selecting one element and considering it the first member of an ordered set. Other elements are selected one at a time to be seriated on a pairwise basis with previously ordered elements. At any time during performance of the task, the previously considered elements or "members" are completely ordered. The selection of the member (ordered element) with which to begin comparing a new element is open, thus allowing for educated guesses. Once a standard has been selected, however, systematic progression up or down the ordered set is employed to locate the correct position for the new element. Poor first guesses will be corrected by this procedure. The strategy requires that the "greater" and "lesser" directions be recalled throughout the task.

The strategy employed in the routine for the seriation variable identification task (Figure 22) involves starting at one end of the spatially ordered set, determining the order of the first pair of elements on the variables being tried, and then carrying out systematic,

TABLE 4

SERIATION TASKS

Task Name	Given Input	Required Output*	Sample Item
Seriation Variable Identification	a set of elements ordered such that their order corresponds to their order on a variable	the name of the variable on which the elements are ordered	Given a set of plants ordered by height. "Why were these plants placed in this order?"
Directed Seriation	a set of elements a variable name	the set of elements ordered on the named variable	Given a set of mineral samples. "Place these samples in order according to their hardness."
Nondirected Seriation	a set of elements	the set of elements ordered on a variable the name of the variable	Given a set of corn seedlings. "Show a way that these seedlings differ by placing them in that order."

*An observation/measurement procedure is required output for each task.

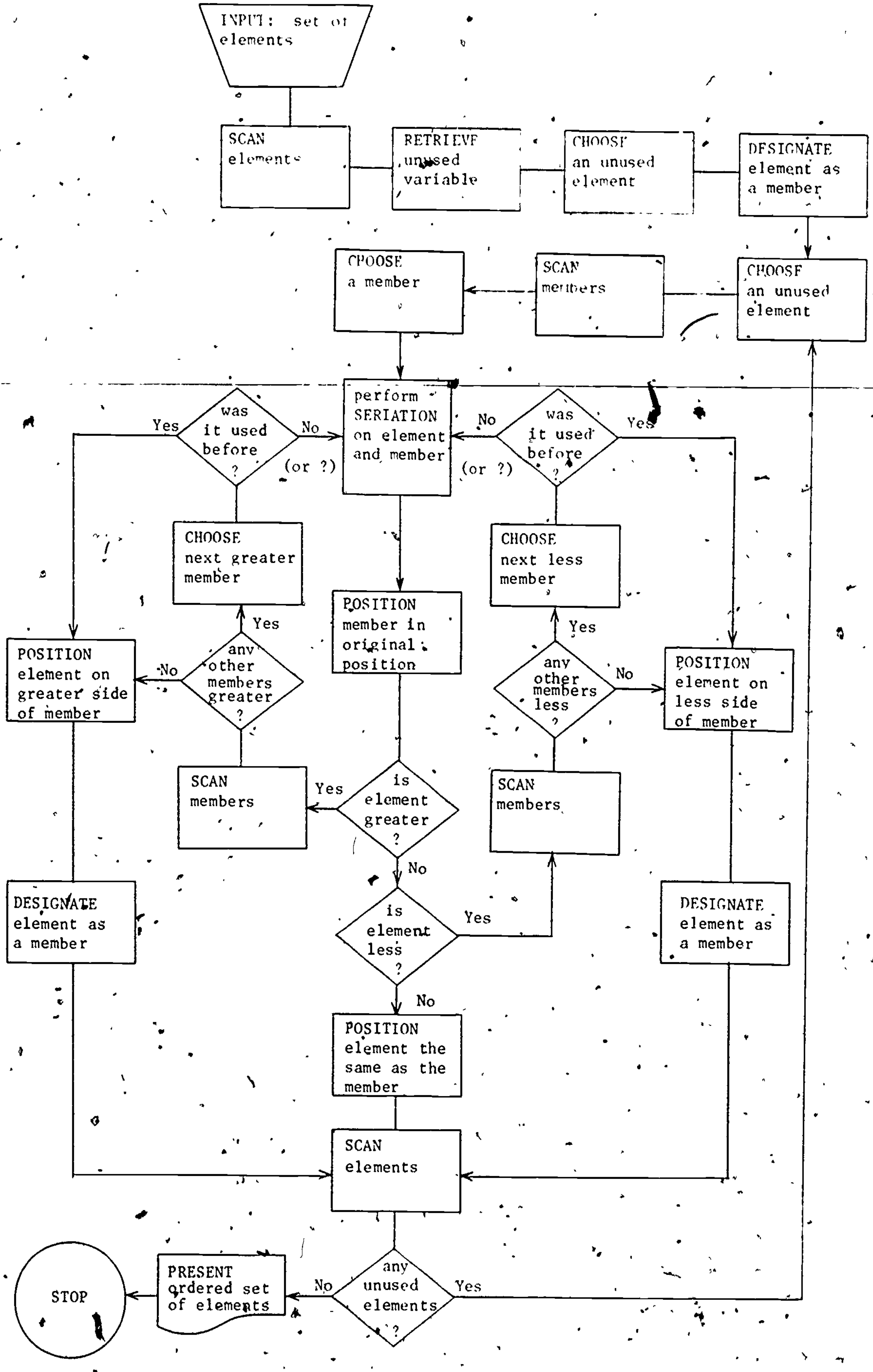


Figure 21. Processing routine for the nondirected seriation task.

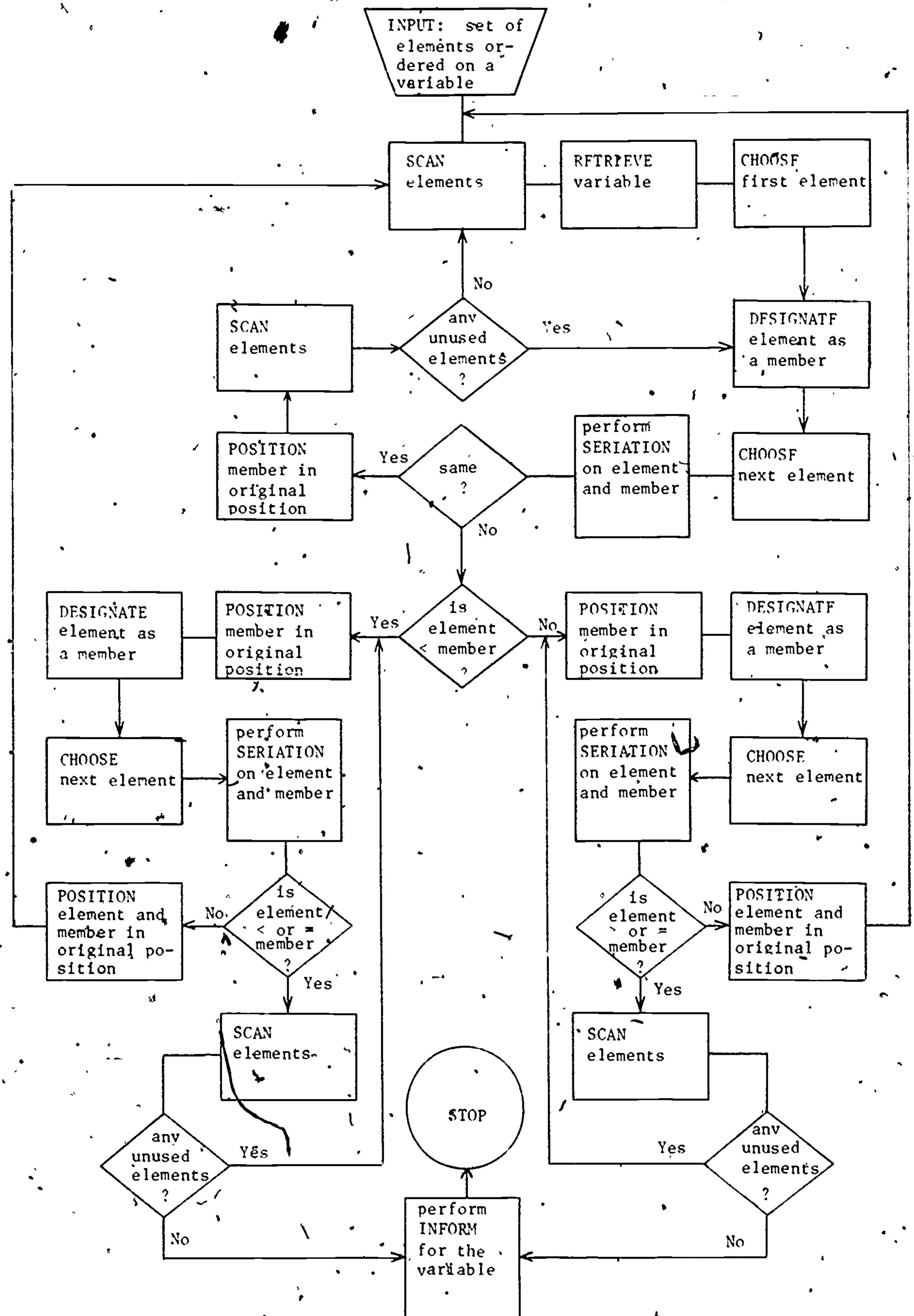


Figure 22. Processing routine for the Seriation Variable Identification (SnV) task.

pairwise comparisons along the set to see if the same order holds for each adjacent pair. If subsequent pairs reverse the order, the routine is begun again and a new variable is tried. Pairs found to be the same on the variable do not effect the result unless all are found to be the same. This strategy requires that the original order of the elements be carefully maintained, i.e., the member and the new element must not be confused.

DISCUSSION

The processing routines presented above describe how their corresponding tasks might be performed. Along with definitions of the fundamental processes, they represent hypotheses about skills involved in task performance. These hypotheses can guide the design of instruction for the tasks. In particular, they provide a basis for specifying outcomes at the skill level, for specifying assessment procedures, for sequencing outcomes, and for identifying useful instructional strategies. Two levels of skills are made explicit in the processing routines presented in this paper, the specific processing skills represented by the primary processes, and the coordinating skills represented by the sequences of processing steps. Specific processing skills must be acquired with each new systemic network (specialized conceptual system) for which the tasks will be performed. For example, the capacities to decode and retrieve variables and variable names, to retrieve and carry out new observation actions, and to select and encode relevant sensory input must be acquired for each new set of systemic content, regardless of previous learning with similar sets of content.

In addition to the specific processing skills, coordinating skills must be acquired which control the sequencing of specific processing steps in carrying out tasks. In the early stages of learning for a task, these coordinating skills may also be specific to systemic networks. As similar processing routines are mastered for each of a series of parallel systemic networks, the sequence of processing steps may become abstracted and represented in a general form. Subsequent execution of a similar routine with a new systemic network can then take place without special instruction so long as the specific processing skills for that network have been acquired in some other context. The abstracted sequence of processing steps is referred to as a strategy. Prior to the functional acquisition of a strategy, the sequences of processing steps must also be acquired for each new systemic network.

IMPLICATIONS FOR SEQUENCING INSTRUCTION

A primary consideration in the sequencing of instruction for a set of tasks is the extent to which they involve common skills. A preliminary determination of these relationships can be made by comparing the processes and strategies involved in the processing routines. Table 5 indicates the fundamental processes involved in the routines for each of the tasks analyzed. The table shows that all the routines involve about the same number of different primary processes (10 to 12). Furthermore, there is considerable similarity in the primary processes involved in the different routines. Seven of these (SCAN, CHOOSE, RETRIEVE, ACT, SELECT, ENCODE, and COMPARE) are used in every routine.

TABLE 5

UTILIZATION OF FUNDAMENTAL PROCESSES IN TASK ROUTINES

	Primary Processes*																Secondary and Tertiary Processes					
	SCAN	CHOOSE	RETRIEVE	ACT	SELECT	ENCODE	COMPARE	DESIGNATE	PLACE	DISCARD	DECODE	REPORT	PRESENT	ORDER	POSITION	SEARCH	COMPARISON	SERIATION	MATCH	MATCH-1	NONMATCH	INFORM
Directed Description	x*	x*	x*	*	*	*	*			*	x	x				x	x			x		
Nondirected Description	x*	x*	x*	*	*	*	*			*	x	x				x	x			x		
Element Selection	x*	x*	x*	*	*	*	x*		*	*	x					x	x		x			
Directed Comparison	x	x	*	*	*	*	*	x	x		x	x					x					
Nondirected Comparison	x	x	x*	*	*	*	*	x	x			x					x					x
Similarity Subset Form	x*	x*	*	*	*	*	*	x	*	x*	x		x				x		x			
Difference Subset Form	x	x	*	*	*	*	*	x	*	*	x		x				x				x	
Similarity Variable i.d.	x	x	x*	*	*	*	*	x	x			*					x					x
Difference Variable i.d.	x	x	x*	*	*	*	*	x	*	*		*					x				x	x
Directed Sorting	x*	x*	*	*	*	*	*	x	*	x*	x		x				*		x			
Nondirected Sorting	x*	x*	x*	*	*	*	*	x	*	x*			x				*		x			
Sorting Variable i.d.	x	x	x*	*	*	*	*	x	x*	*		*					*				x	x
Directed Seriation	x	x	*	*	*	*	*	x			x		x	*	x		*	x				
Nondirected Seriation	x	x	x*	*	*	*	*	x					x	*	x		*	x				
Seriation Variable i.d.	x	x	x*	*	*	*	*	x				*		*	x		*	x				x

*These processes are utilized as parts of secondary or tertiary processes.

DESIGNATE, which assigns a particular role (e.g., "model") to an element for processing purposes, is employed in all the routines except for those for the description tasks. All of the routines utilize spatial placement--PLACE, DISCARD, and/or POSITION--to represent decisions made about elements. The verbal processes DECODE and REPORT are used in some of the routines for each of the basic kinds of task (description, comparison, sorting and seriation). The tasks which do not require REPORT do require PRESENT, usually a nonverbal presentation of the results of a task. SEARCH is utilized only in the description tasks where sets of standard elements are required.

The sequencing of tasks on the basis of the specific processing skills involved assumes that one task requires only a subset of the skills required in another. Although there is a considerable overlap in the specific processing skills required for the tasks analyzed, no hierarchical pattern is evident. This is not unexpected since these tasks were all selected as terminal tasks. If additional, en route tasks are required, they will have to be selected using a hierarchical relationship to the tasks analyzed in the present paper as a criterion. The processing routines can be used to generate such tasks. Portions of a routine can often be made into separate tasks by adding appropriate input and output steps.

Consideration of the coordinating skills involved in tasks is also important in sequencing instruction. For example, the processing routine for the similarity subset formation task (Figure 13) involves choosing one element which is designated as a model and then comparing it to each of the other elements, placing those which are similar to it in a group and discarding all the others. In the sorting tasks (Figures 17 and 18), this same sequence is used repetitively until all the elements have been placed in some group. Performing the sorting task is not exactly like performing the similarity subset formation task several times since, in the sorting task, the discarded elements from one cycle must be designated as the unused elements for the next, and the recycling must be contingent on there being unplaced elements. However, the subset formation task routine forms the core of the sorting task routine. Considerable positive transfer to the learning of the sorting task routines would be anticipated from the prior learning of the subset formation task routine.

A sharing of common coordinating skills is indicated by the occurrence of the same secondary or tertiary process in two or more processing routines. As indicated in Table 5, every task routine involves the COMPARISON secondary process (Figure 3). The sequence of primary processing steps involved (RETRIEVE, ACT, SELECT, ENCODE, and COMPARE) represents a core of skills basic to the performance of all the tasks analyzed. ORDER is added to the sequence in the SERIATION tertiary process (Figure 4). The similarity subset formation and sorting tasks discussed above share the MATCH tertiary process (Figure 5). This process identifies a subset of elements similar to a model element on a specific variable. MATCH is also used in the element selection task routine. Two other task routines use a similar tertiary process, MATCH-1 (Figure 6), which terminates when one element has been found which matches the model.

Three task routines utilize the NONMATCH tertiary process (Figure 7) to determine whether or not new elements differ from all members of a given set. This process is part of a strategy common to the difference subset formation task (Figure 14), the difference variable identification task (Figure 16) and the second part of the sorting variable identification task (Figure 19). This strategy involves the repetitive use of NONMATCH to identify a set of elements all of which differ from one another on a variable, or to determine whether or not a set of elements meets that criterion.

Several tasks require the performer to report the identity of the variable with which the task has been carried out. The routines for these tasks employ the INFORM secondary process. In this process the preferred response is to name the variable. However, if the variable name cannot be retrieved, values which describe the elements on that variable may be used (e.g., the subset formation tasks, Figures 13 and 14).

In addition to the sequences of processing steps identified as secondary or tertiary processes, certain short sequences of primary processes recur in several routines. One such sequence is the SCAN-CHOOSE-DESIGNATE sequence which arbitrarily designates one element as the first member of a particular subset. In some cases the element is designated as the model for a subset of elements, all of which will be similar to it on a particular variable (e.g., in the similarity subset formation task, Figure 13). In other cases, the element is simply a member which must be taken into account when any additional elements are considered for membership (e.g., in the difference subset formation task, Figure 14, and the seriation tasks, Figures 3 and 20).

Another short sequence is employed in the routines which recycle until all of a set of elements has been dealt with. This sequence involves a SCAN step with recycling to a CHOOSE step contingent on there being unused elements remaining. This sequence occurs in 13 of the 15 routines and is part of the MATCH, MATCH 1 and NONMATCH processes.

RELATIONSHIPS TO HIGHER LEVEL TASKS

The processing routines for the description tasks utilize COMPARISON with a set of standard elements. By introducing ordered standards for quantitative variables, and then standards representing n unit standards, this strategy leads to a measurement strategy appropriate for additive variables such as weight, length, force, etc. Finally, the set of standards can be replaced by a large number of unit standards (e.g., rods one inch long) from which the observer creates a "standard" which matches the given element on the variable. Measuring devices such as spring scales can be introduced (and calibrated) by observing the effects of varying numbers of unit standards on the device.

The strategies developed for the sorting and seriation tasks provide components of strategies for discovering simple relations between variables (correlations). The strategy for sorting a set of elements can be employed first for one variable followed by use of the sorting variable identification strategy to identify another variable on which the elements were simultaneously sorted. A similar strategy could be employed incorporating the seriation task strategies. Of course the relations discovered would not necessarily hold for elements other than those observed. Strategies for appropriate sampling of sets of elements are required for determining the generality of observed relations between variables. However, the strategies described above would still be useful in dealing with the samples.

The designation of a particular element as a model for a subset in several of the processing routines is reminiscent of the use of an example in the focusing strategies discussed in the concept attainment literature (Bruner et al., 1956). It is quite possible that the simple "focusing" strategy described in this paper could be the first step in the development of more complex strategies which focus on a particular element to systematically generate and/or represent lists of variables, hypotheses, etc.

One of the primary reasons for the selection of the tasks analyzed in this paper as terminal tasks for a primary grade science curriculum was that they function to inform the person performing them, i.e., they represent useful inquiry tasks. However, unless learning these tasks contributes to the performance of higher level tasks further along in the curriculum, their impact on the total inquiry behavior of the learner will be minimal. It was anticipated that the tasks selected could be used to facilitate the learning of routines for higher level tasks. The above examples of relations between the routines presented in this paper and higher level tasks provide additional support for this assumption.

IMPLICATIONS FOR INSTRUCTIONAL PROCEDURES

The processing routines described above provide direct input for designing instructional procedures. Three kinds of instructional procedures are immediately apparent: 1) demonstration, 2) guided performance, and 3) task decomposition. As implied by the name, the first procedure involves step-by-step demonstration of the processing routine to the learner prior to requiring him to execute it. In the guided performance procedure, the learner is guided step-by-step through the routine prior to being required to execute it independently. In the task decomposition procedure, the learner masters a set of subordinate tasks which utilize components of the original routine before he is required to perform the routine in its entirety. In many cases, instruction may usefully employ combinations of these procedures.

Both the demonstration and guided performance procedures can vary in the level of detail of verbal information provided as explanations or instructions. In the case of demonstration, the verbal information would direct attention to what the demonstrator is doing. In the case of guided performance, the verbal information would inform the learner, in the context of the item, what to do next.

Consider the similarity subset formation task routine (Figure 15) as an example. Demonstration and guided performance instructional procedures for this routine are illustrated in Table 6. The item involves forming a subset of sea shells having the same shape. Much the same verbal information is provided for the two procedures.

TABLE 6

SAMPLE DEMONSTRATION AND GUIDED PERFORMANCE INSTRUCTIONAL PROCEDURES FOR THE SIMILARITY SUBSET FORMATION TASK

Demonstration Procedure	Guided Performance Procedure
A group of sea shells is presented.	A group of sea shells is presented.
"I am going to find some shells which are the same shape."	*"I am going to help you to find some shells which are the same shape."*
"First I am going to choose one shell to use as a model."	*"First, choose one shell to use as a model."*
A shell is chosen.	A shell is chosen.
"Now I can find the ones that are the same shape as my model."	*"Now you can find the ones that are the same shape as your model."*
"I'll find another shell and see if it is the same shape as my model."	*"Find another shell and see if it is the same shape as my model."*
A second shell is chosen and compared to the model.	A second shell is chosen and compared to the model.
"This shell is the same shape as the model, so I will put it in a special place right in front of me."	*"Is it the same shape as the model?"*
The shell is placed in front of the demonstrator but apart from the unused shells.	Yes ___ *"Put it in a special place right in front of you."*
"It is not the same shape as the model so I will put it off to the side so I won't choose it again."	No ___ *"Put it off to the side so you won't choose it again."*
The shell is placed to the side, well away from the unused shells.	The learner puts the shell in the appropriate location.
etc.	etc.
When all the shells have been compared with the model, the last part of the routine is carried out.	When all the shells have been compared with the standard, the last part of the routine is carried out.

Demonstration Procedure	Guided Performance Procedure
"There are no more shells to look at."	*"Are there any more shells to look at?"* No
"The model is the same shape as all these, so I will put it here, too."	*"The model is the same shape as all those in the special place, so you can put it there too."*
"All these shells have the same shape."	*"Show me some shells which have the same shape."*
Demonstrator gestures, indicating the shells placed together in front of him.	The learner gestures, indicating the shells placed together in front of him.

The illustrated procedures assumed that the learner had previously learned about the shape variable. If this were not the case, then a task decomposition procedure might be employed. A task routine could be formed which did not require DESIGNATE, PLACE, DISCARD, or any recycling; it would include just the COMPARISON process and some simple input and output steps. Such a routine is illustrated in Figure 23.

It is quite likely that all these kinds of instructional procedures will be useful with the tasks analyzed in this paper. The processing routines should prove very useful in generating instructional alternatives using these kinds of procedures.

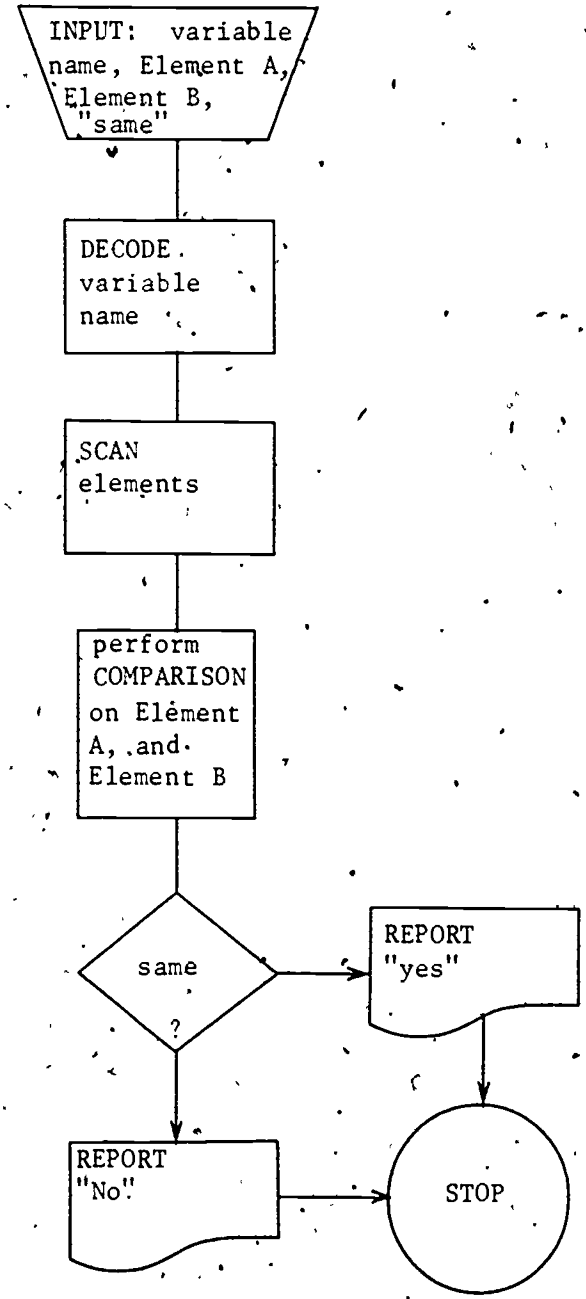


Figure 23. Processing routine for a task subordinate to the similarity subset formation task.

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ABSTRACTS OF RELATED DOCUMENTS

TN 2-71-12. Edward L. Smith and K. Roger Van Horn. Conventions for Analyzing Skill Areas in the K-3 Curriculum, August 9, 1971.

Conventions are presented for use in analyzing instructional outcomes in portions of K-3 science, mathematics, and communication skills. Based on the conventions, three operations commonly required in K-3 science, mathematics, and communication skills are defined: a) description; b) application of relational rules; and c) application of rules of correspondence. Outcomes can be analyzed in terms of the events, objects, or other elements with which children are expected to deal, and the operations which children are expected to perform. Set and matrix notational conventions are also presented.

TN 2-72-58. Edward L. Smith and Janis J. McClain. Content Analysis of Selected Primary Level Units of the Science Curriculum Improvement Study, December 7, 1972.

To evaluate a method of content analysis, and as a step toward the specification of a conceptual domain for primary level science, extant instructional programs were analyzed. This paper reports an analysis of the introductory unit and three biological science units of the Science Curriculum Improvement Study. The background of the program and the procedures for the analysis are described. The conceptual content is summarized. Problems encountered in the analysis and their implications for subsequent analyses are discussed.

TN 2-72-59. Janis J. McClain. Content Analysis of Selected Units of the First-Grade *Concepts in Science* Program, December 19, 1972.

To further evaluate a method of content analysis and aid in identifying scientific concepts appropriate at the elementary level, science material in a standard textbook was examined. The present paper reports and summarizes the analysis of sections of the California state-adopted textbook series, *Concepts in Science*. The conceptual structure of the program is described and compared with the structure of the previously analyzed *Science Curriculum Improvement Study*. Problems encountered in the method of analysis are reported.

TN 2-73-46. Edward L. Smith. Toward a Scientific Inquiry Program Architecture, November 26, 1973.

This paper presents an overview of a scientific inquiry program, describes the components of the architecture that have been completed, and outlines further design and development steps.